26. *The* Pliocene Deposits *of the* East *of* England: *The* Lenham Beds *and the* Coralline Crag.

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(Read March 9th, 1898.)

I. Introduction.

The Pliocene deposits of the East of England have been studied for many years, and by many competent observers, but, unfortunately, no general consensus of opinion has been arrived at, either as to their systematic arrangement, or the conditions under which they originated: the views, for example, of Sir Joseph Prestwich, which have obtained considerable acceptance, differing in many important respects from those of the equally eminent authorities Mr. Searles V. Wood and his son.

Prestwich, in his well-known paper,[1] divided the Coralline Crag into eight constant and determinable zones, and, on the other hand, regarded the Red Crag as forming two divisions only: the lower, including the deposits of Walton-on-the-Naze, Sutton, Bawdsey, Butley, Sudbourne, and Aldeburgh,[2] and the upper, consisting of what he originally called 'the unfossiliferous sands of the Crag' (now believed to be a part of the deposit which has been deprived of its shells by the infiltration of water containing carbonic acid)[3] and of the Chillesford Beds. The Norwich Crag, with which he grouped some deposits containing *Tellina balthica*, he held to be equivalent, partly to his lower (namely, to the Crag of Walton, Sutton, Butley, etc.), and partly to his upper or Chillesford division.[4]

I still hold, for reasons to be given hereafter, that there is no sufficient evidence for dividing the Coralline Crag into the eight zones proposed by Prestwich; indeed, I now believe that the tripartite arrangement, formerly adopted by Mr. Wood, jun., and myself,[5] can be no longer maintained, and that the Coralline Crag is practically one formation, of the same character, and deposited throughout under similar conditions. With a series of beds 60 feet in thickness, there is, however, necessarily some difference in age between those which occur at any one place in vertical section.

As to the Red Crag, the facts which I propose to offer in a succeeding paper will show, I think, that the division of this formation into four zones, proposed by S. V. Wood, sen., in 1866,[6] represented by the deposits occurring at Walton, Sutton, Butley, and

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 121, fig. 4.
[2] *Ibid.* p. 354.
[3] Wood & Harmer, and Whitaker, *ibid.* vol. xxxiii (1877) pp. 75 & 122.
[4] *Ibid.* vol. xxvii (1871) pp. 471–73.
[5] Suppl. 'Crag Mollusca,' Introd. p. iii, Monogr. Palæont. Soc. 1872.
[6] Quart. Journ. Geol. Soc. vol. xxii, p. 538.

Chillesford respectively, still holds good, and further that there are Red Crag-beds which do not exactly correspond with those found at any of these localities, which may therefore be conveniently separated from them. The various Red Crag-beds are, in my opinion, the marginal accumulations of a sea gradually retreating northward and eastward, in consequence of the earth-movements described in my paper on 'The Pliocene Deposits of Holland.'[1] The molluscan fauna of the different exposures of the Red Crag assumes a more recent and a more boreal character as we trace them successively in a north-easterly direction, and they arrange themselves therefore in horizontal rather than in vertical sequence.

I still consider that the Crag of Norfolk and of the northern part of Suffolk is newer than any part of the Red Crag, except perhaps that which occurs in the upper part of the section in the Stack-yard pit at Chillesford; and that the Weybourne and Belaugh beds, containing *Tellina balthica*, mark a yet more recent horizon of the Pliocene period.

Early in Red Crag times, I believe, the communication which had previously existed between the North Sea and the English Channel was interrupted,[2] and in consequence southern species of mollusca became by degrees less abundant in the former, and finally disappeared from it, while, coincidently, an invasion of the Crag area by boreal and arctic forms took place. Hence, if we can trace out the history of the gradual disappearance of the southern, and of the gradual arrival and increasing abundance of the northern shells, and if we can ascertain the relative proportion of these different groups at different localities, we shall have the material at hand for correctly classifying the various beds of the Upper Crag.

The old lists of the Crag mollusca as a rule did not distinguish between the rare and the abundant species, and therefore the conclusions drawn from them are not wholly reliable. To attach the same importance, for the purpose of analysis, to a species of which a single specimen, or at the most a very few, may have been discovered as the result of the labours of nearly a century, as to one of which a hundred specimens may be easily obtained in the course of a few minutes, is obviously misleading. The collections in our museums are not so instructive as they would be if the efforts of collectors were not so largely directed to the acquisition of rare species and of perfect specimens. From a geological point of view, it is the abundant rather than the rare species which are important, and shells which are seldom found in collections, as it is difficult to obtain them whole, are sometimes among the most characteristic of the deposit in which they occur. In order to ascertain the age of a bed or the character of its fauna, it is necessary to count specimens, so to speak, rather than species.

Much more attention than formerly has been paid of late years to this point, but the Crag mollusca as a whole have not been so dealt with. In the lists which I hope to publish with my next paper, I

[1] Quart. Journ. Geol. Soc. vol. lii (1896) p. 748.

[2] See also Prestwich, Quart. Journ. Geol. Soc. vol. xiv (1858) p. 331.

shall attempt to distinguish between those forms which I think may, and those which may not be considered as representative of each bed. It is difficult in some cases to know where to draw the line, and possibly the experience of other collectors may not always coincide with my own; I hope, however, that reliance may be placed on the general conclusions to be drawn from my lists.

II. The Lenham Beds.

Our knowledge of the Lenham fossils is principally due to Mr. Clement Reid, who from the most unpromising material has succeeded in obtaining from that locality a collection of 61 species of mollusca, not including 6 as to the identification of which he is in doubt.[1] This list, though doubtless containing but a small proportion of the molluscan fauna of the period, may possibly be considered as fairly representing it.[2] The 67 species named belong to 50 genera, and they are more or less of a character similar to those found in the Coralline Crag. With the exception of 15 (or 23 per cent.), they all occur in that deposit.

In the work just mentioned [3] Mr. Reid groups the Lenham Beds with the sands of Louvain and Diest, and with the fossiliferous strata of Antwerp and Utrecht, and, taking them as a whole, he considers that they are of the same age as, or even slightly newer than, the Coralline Crag. I have given elsewhere my reasons for believing that some of the strata met with in the Utrecht boring, regarded by Dr. Lorié[4] as Diestien, belong to the Scaldisien, that is, to a more recent formation,[5] and I do not think that any of them are as old as those of Lenham. The sands of Diest and Louvain, including the zone à *Terebratula grandis*, are now believed by Belgian geologists, and I think with reason, to be older than the Antwerp beds (zone à *Isocardia cor*). It is the latter zone only, and not the whole of the deposits generally known as Diestien, which represents, I consider, the Coralline Crag of Suffolk, 87 per cent. of the mollusca from the *Isocardia*-beds occurring also in the latter. On both palæontological and stratigraphical grounds, I believe that the Lenham Beds, although undoubtedly of Pliocene age, as held by Prestwich and Wood, may be considerably older than the Coralline Crag.

[1] Mem. Geol. Surv. 'Pliocene Deposits of Britain,' 1890.

[2] [In the discussion which followed the reading of this paper, Mr. Reid suggested that if the smaller forms of the Lenham fauna were known, its general character might appear to be different. He considers that 'the smaller mollusca generally give a larger percentage of persistent forms.' I doubt this very much. An examination of the molluscan fauna of the Coralline Crag, the other deposit in question, does not seem to me to lend any support to such a view.—May, 1898.]

[3] *Op. cit.* p. 57.

[4] 'Contrib. à la Géol. des Pays-Bas,' No. 1, Extr. des Archives du Musée Teyler, Haarlem, ser. ii, vol. ii (1885).

[5] Quart. Journ. Geol. Soc. vol. lii (1896) p. 762. It does not seem to me that any of the Pliocene deposits described by Dr. Lorié are older than the Coralline Crag.

The names of the 15 species found at Lenham, but not in the Coralline Crag, are as follows:—

Extinct Forms.	Miocene.	Italian Pliocene.	Red Crag.
Terebra acuminata, Bors.	*	*	
Triton heptagonum, Broc.	*	*	
Pleurotoma consobrina, Bell.	*		
„ *Jouanetti*, Desm.	*		
„ *turrifera*, Nyst [1]	*	*	possibly derivative.
Xenophora, sp.			
Pecten, sp. nov.			
„ sp. nov.			
Cardium, sp. nov.			
Tellina Benedenii, Nyst [1]	?		*
Southern Forms.			
Arca diluvii, Lam.	*	*	
Cardium papillosum, Poli	*	*	
Gastrana fragilis, Linn.	*	*	
Northern and Southern.			
Nucula sulcata, Bronn	*	*	
Trochus cinerarius, Linn. (North African)		*	*

Besides employing the time-honoured method of testing the comparative age of any Tertiary horizon, namely, by observing the proportion between its recent and extinct shells, we may go a step farther back, and enquire what percentage were survivors from earlier, that is from Miocene seas, or may have existed at the same period elsewhere, under different conditions, in deposits which, though contemporaneous, are not homotaxial.

The resemblance of the molluscan fauna of the Coralline Crag to that of the Mediterranean at the present day has often been emphasized, but a similar correspondence exists, and for the same reason, between the molluscan fauna of the Miocene deposits of Northern Europe and that of the Pliocene of Italy and Sicily. Many species which flourished in the North Sea during the Coralline Crag period have now become extinct there, but they continue to exist in the Mediterranean; so, dealing with an earlier period, we find that a large number of mollusca occurring in the Belgian[2] and North German Miocene,[3] which had disappeared from these latitudes before the

[1] Found also in the Diestien Beds of Belgium.

[2] Van den Broeck, 'Esquisse Géol. & Paléont. des Dépôts Plioc. d'Anvers,' 1876, p. 40, etc.

[3] Von Kœnen, 'Mioc. Nord-Deutschl. u. seine Molluskenfauna,' Cassel, 1872; Stuttgart, 1882.

deposition of the Coralline Crag, still survived in the older Pliocene seas (Piacentian) of Southern Europe.[1] The Pliocene deposits of the Mediterranean thus represent, in a sense, an older fauna than do those of similar age in the Anglo-Belgian basin. Now, not only do the Lenham Beds contain a somewhat larger percentage of extinct species, but they are more closely connected with the Miocene on the one hand, and the Pliocene of the Mediterranean on the other, than is the Coralline Crag, as shown by the following numbers:—

	Species still existing.	Occurring in Miocene deposits.	In the Pliocene of the Mediterranean.
Lenham.....	57 per cent.	75 per cent.	72 per cent.
Coralline Crag ...	61 „	59 „	61 „

These three independent methods of testing its fauna agree in indicating that the Lenham Beds are older than the Coralline Crag. In the foregoing comparison I have taken only the more abundant species of the latter. If the rarer forms had also been included, the difference between the two deposits would have been still greater. The list of Lenham mollusca is not likely to contain any but species which are more or less characteristic.

The view that the Lenham deposit is older than the Coralline Crag seems to be confirmed by a more particular examination of its molluscan fauna. In addition to the species enumerated in the preceding table (p. 311) we find at Lenham the following similarly characteristic Miocene or Italian Pliocene forms, namely:—

Fusus lamellosus, Bors.	*Cancellaria contorta*, Bast.
Pyrula reticulata, Lam.	*Hinnites Cortesyi*, Defr.

These occur but rarely in the Coralline Crag, and were probably beginning to die out in the Anglo-Belgian area during its deposition. There is one species, however, *Arca diluvii* (which Mr. Reid informs me is one of the most abundant Lenham fossils), the presence of which at that locality is specially significant. This mollusc, widely diffused during the Miocene epoch, and very common in the Bolderien of Belgium, seems to have disappeared from the North Sea before the Coralline Crag period,[2] no trace of its existence having been met with either in that formation or in any of the Diestien deposits of Belgium or Holland, but it still continued to inhabit the Mediterranean during the Pliocene era, as it does to this day.

Another species, *Cardium papillosum*, may be also mentioned. This Miocene and southern form, existing in the Mediterranean both in Pliocene times and at present, is unknown from any of the Pliocene deposits of Belgium or East Anglia, but it is one of the most abundant Lenham fossils. It may be noticed, on the other hand, that the different species of *Astarte*, which occur in the Coralline Crag in

[1] As the climate of the Pliocene period changed, certain species died out, but they continued to exist longer in southern than in northern latitudes.

[2] *Arca diluvii* is said by MM. Viellard & Dollfus to occur, but only in the oldest portion of the Pliocene of Normandy, 'Etude Géol. sur les Terrains Crét. et Tert. du Cotentin,' Caen, 1875, p. 154.

such countless profusion, are equally rare at Lenham and in the Miocene deposits of Belgium.

The fauna of the *Isocardia cor*-beds of Belgium, which resembles so closely that of the Coralline Crag, presents, on the contrary, no such marked affinities with the Miocene and the Italian Pliocene deposits.

While thus the Lenham fauna contains at least 13 (out of 61) characteristic Miocene or Italian Pliocene species, unknown or rare in any North Sea deposit later than the Miocene, not a single mollusc (the undescribed forms perhaps excepted) has been met with at Lenham which has not also been found in beds as old as the Coralline Crag. The mollusca occurring at Lenham, but not in the latter, are therefore almost entirely of an older rather than of a newer type, 10 out of the 15 before mentioned being extinct and 3 southern.

The evidence of the Lenham polyzoa is not of great value, 2 species only being known to Mr. Reid, but, so far as it goes, it points in the same direction. One of these, *Fascicularia aurantium*, is extinct, and the other, *Cupularia canariensis*, a form still existing, ranges no farther north than Madeira or the Canaries. The polyzoan fauna of the Coralline Crag, on the contrary, includes many species which are found in British seas.

Mr. Reid indeed insists that the fossils from Lenham present a more decidedly southern (but therefore, I suggest, older) facies than do those of any other of the recognized Pliocene deposits of the Anglo-Belgian area. The present distribution of mollusca in the British seas seems to be largely due to tidal currents which carry forward the free-swimming larvæ as far as their influence extends. As will be seen hereafter, the tidal currents which reached the Coralline Crag area probably came, not from the north, but from the south—that is, from the direction of Lenham. It seems, therefore, to me more reasonable to suppose that the southern and Miocene forms found at Lenham, but not in the Coralline Crag, had died out in these latitudes previously to the deposition of the latter, than that two faunas differing so considerably one from the other should have co-existed in the same basin, and under similar conditions as to current-action, within 60 miles of each other. No such difference in geographical distribution as this is known to occur in British seas at the present day.

The question of the origin of the 'boxstones' found in the nodule-beds at the base of the Coralline and Red Crags may be conveniently discussed at this point. They are composed of fine ferruginous material, not unlike that of some of the Diestien or the Lenham sandstones, and are rounded and waterworn, resembling in shape the beach-pebbles of flint now found in places on the Norfolk coast. Mr. Reid believes that they have been derived from a single horizon, which is not of Miocene age,[1] and with this con-

[1] Mem. Geol. Surv. 1890, 'Pliocene Deposits of Britain,' p. 12, etc. See also Ray Lankester, Quart. Journ. Geol. Soc. vol. xxvi (1870) p. 500.

clusion I agree entirely. The mollusca obtained from the boxstones, although not identical with those from Lenham,[1] are generally of a similar character, including *Conus Dujardinii*,[2] *Nassa conglobata*, *Voluta auris-leporis*, and *Isocardia lunulata* (characteristic fossils of the Miocene deposits of the North Sea, or of those which I regard as to some extent representing them, namely, the Pliocene deposits of the Mediterranean), associated with other forms of a more modern, but still Coralline Crag type.

The marine vertebrata of the nodule-beds include also a similar admixture of Miocene and Pliocene forms, as, for example, *Herpetocetus scaldiensis*, *Hoplocetus crassidens*, and *Squalodon antwerpiensis*, said to occur in the Bolderien deposits of Antwerp together with species of Diestien age.[3]

Thus the boxstone fauna seems to be much of the same intermediate character, between those of the Miocene of Belgium and of the Coralline Crag, as is that of Lenham; and I am inclined to agree with Prof. Ray Lankester that it is from a former extension of a deposit of similar, though possibly not identical age, that the boxstones and some other extraneous fossils found in the nodule-beds have been derived.[4]

The stratigraphical evidence lends, I think, some support to this hypothesis. It has been often pointed out that the Lenham Beds are connected by a chain of outliers with the sands of Louvain and Diest, and they are probably contemporaneous with some part of them. The upheaval which has affected these deposits has been greatest in Kent, where they occur 620 feet above the sea-level; but their height becomes gradually less, until at Louvain it is barely 200 feet. They have been everywhere extensively denuded, except east of Louvain (see map, fig. 1, p. 316), where they cover the country with a continuous sheet; but they dip towards the north-west, and beyond Malines disappear under newer beds.

Since the publication of my paper on the Pliocene deposits of Holland, an important communication from the pen of M. Rutot, the distinguished Belgian geologist, has appeared,[5] with maps showing the probable extension of the North Sea over Belgium at the commencement and towards the end of the Diestien period; the boundaries there given I have reproduced in the accompanying map (fig. 1) by the kind permission of M. Rutot. That to the south indicates the southern margin of the sea in which an earlier part of the formation, namely, the sands of Louvain and Diest, zone à *Terebratula grandis* (and, as I think, of Lenham), originated, and that to the north the limits of the basin of the later portion, the zone à *Isocardia cor*.

As the earth-movements which affected Holland and Belgium were

[1] The Lenham fauna must have contained many species which are not at present known from that locality.

[2] *Conus Dujardinii* occurs also in the older portion of the Diestien beds of Belgium (zone à *Terebratula grandis*).

[3] Van den Broeck, 'Esquisse Géol. & Paléont. des Dépôts Plioc. d'Anvers,' pp. 68 & 120.

[4] Quart. Journ. Geol. Soc. vol. xxvi (1870) p. 501.

[5] 'Les Origines du Quaternaire de la Belgique,' Mém. Soc. Belge de Géol. vol. xi (1897) p. 1.

felt also in this country, it may be that in the width of the belt of the Diestien sands between Louvain and Malines we have an approximate measure of the recession of the sea which took place in England between the Lenham and the Coralline Crag periods, and I have ventured so to show it on the map. If this view be correct, it is not difficult to understand that the cliffs which fringed the southern shore of the Coralline Crag sea may have included beds of Lenham or approximate age, from the destruction of which the beach-pebble-like boxstones were derived. They could hardly have come from a Miocene source. There is no indication that the sea of the Bolderien period approached the shores of East Anglia, or that it was connected with the Atlantic towards the south-west.[1] It was not until after the close of the Miocene epoch, and in consequence probably of the great disturbances which then ensued, that the German Ocean encroached upon the land over the east of Belgium and the Pas-de-Calais, towards Kent, opening up communication with seas to the south-west.[2] Moreover, the elevation of the southern part of the Tertiary basin was accompanied by a corresponding depression towards the north, so that the Miocene strata of Belgium were at that period, in all probability, submerged and covered by Diestien beds, and so protected from denudation.

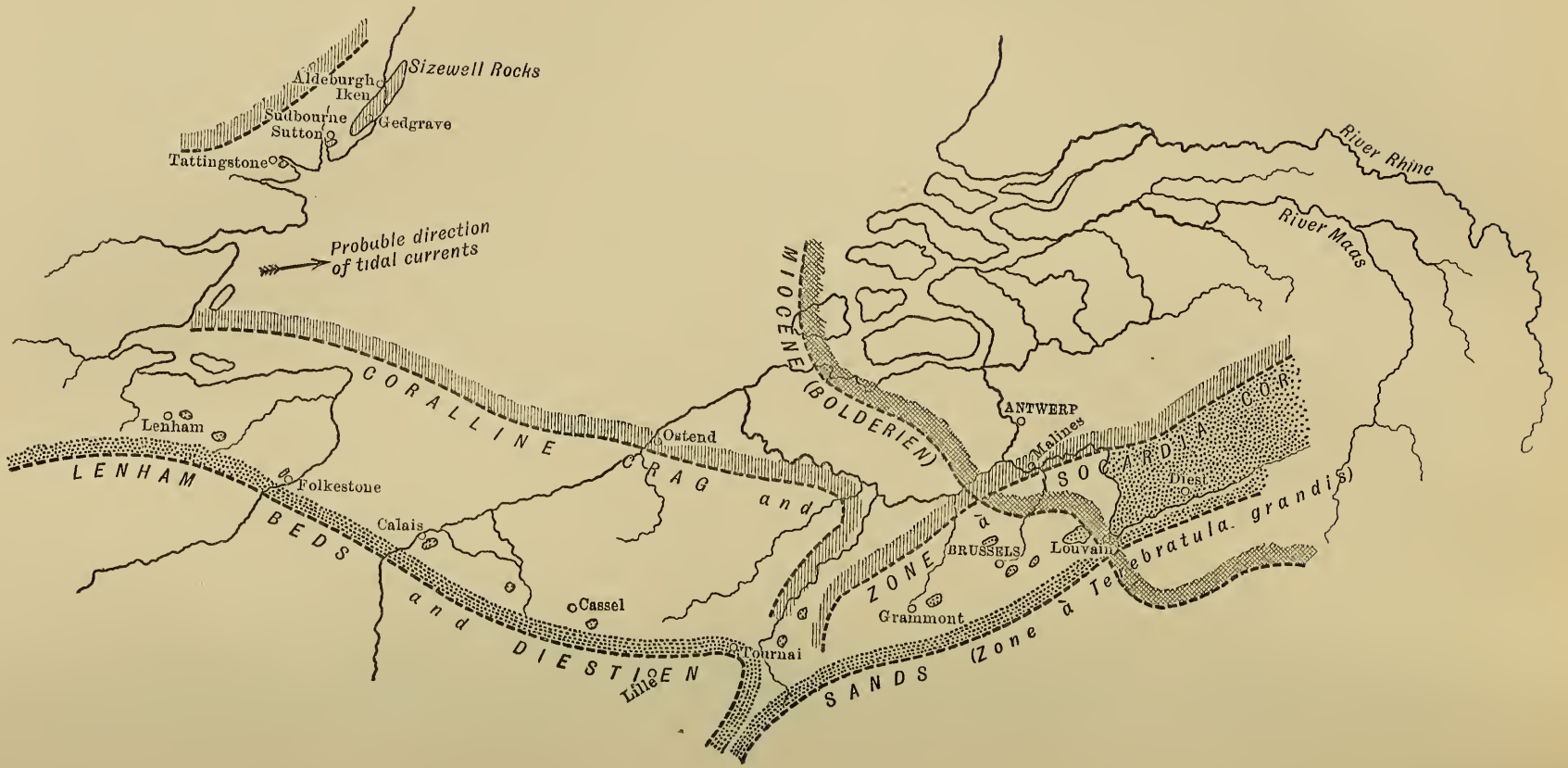
It is difficult, therefore, from a stratigraphical point of view, to find any other source for the boxstones than the older Pliocene sandstones of the South of England, which, like some part of the sands of Louvain, had, I consider, been elevated into land before the deposition of the Coralline Crag. Originating, probably in the first instance, as beach-pebbles, the boxstones may have travelled as littoral drift along the western margin of the Crag sea,[3] or they may have been brought to their present resting-place by the southern currents then prevailing. It should be noticed that they occur almost entirely in one part of the Crag district. That they are found in the same area under both the Coralline and the Red Crags seems a difficulty, because those two formations must have originated under different conditions. Possibly the nodule-bed

[1] I have indicated in the map (fig. 1, p. 316) the southern and western limits of the Bolderien sea, according to M. Rutot.

[2] It may be noticed that in the Coralline Crag Miocene shells occur which are found in the Faluns of Touraine, but are not known from the Belgian and North German Miocene.

[3] The travel of the beach along the south coast of England is now, as it always must have been, from west to east—that is, in the direction of the flowing tide. 'The head of the tide,' namely, the point at which the tidal currents running down the eastern coast of England and up the English Channel meet (see Kinahan, Quart. Journ. Geol. Soc. vol. xxxiii. 1877, p. 31), is situated at present in the immediate neighbourhood of the Straits of Dover. If the North Sea during the Coralline Crag period was less open to the north than it is at present, as seems probable (see p. 351), the position of the head of the tide would have been situated farther north than it is now, and the influence of the tidal currents from the south would then have been felt off the coast of Suffolk. The fact that southern currents do not now penetrate to any extent into the German Ocean is probably the reason why so few of the southern species of mollusca found in the English Channel and on the western coast of England occur on the shores of Norfolk. (See Trans. Norfolk & Norwich Nat. Soc. 1871–72, p. 42.)

Fig. 1.—*Map showing the probable western and southern limits of the German Ocean during the Miocene, and at the commencement and towards the end of the Diestien period.* (Scale: $\frac{1}{2{,}500{,}000}$ = about 39 miles to the inch.)



was accumulated previously to the deposition of the Coralline Crag, or cliffs of older Pliocene sandstones may have continued to exist along the south-western margin of the Crag sea during a part of the Red Crag period.

If the conclusions to which the facts here enumerated seem to point be correct, the Lenham Beds may be considerably older than the Coralline Crag, these two deposits being separated from each other by an interval sufficiently long to allow for the consolidation and subsequent denudation of the former,[1] as well as for the disappearance from the Anglo-Belgian basin of a number of species of mollusca which abounded in it during the Miocene, and continued to do so until the earlier part of the Pliocene period.

Although the Lenham Beds are connected stratigraphically with the sands of Louvain and Diest, the molluscan faunas of the two deposits, while presenting some resemblance, are, as to individual species, by no means identical. The difference may be due to the fact that the collection of fossils from either is small, and therefore imperfect; or the Diestien Sands may represent a considerable period, and the fossiliferous beds which they contain may be of a somewhat later age than the Lenham deposit. Fossil shells are not common in these sands, and when they do occur it is in the form of casts, which is also the case at Lenham.

The species known from the Diestien Sands (zone à *Terebratula grandis*) are the following:—

List of Mollusca from the Diestien Sands of Belgium.

	Lenham or Box-stones.	Miocene or Ital. Pliocene.	Cor. Crag.	Extinct.
Voluta Lamberti, Sow.	*	*	*	*
Nassa labiosa, Sow.	...	*	*	*
„ *reticosa*, Sow.	...	...	...	*
„ var. *elongata*, S. V. W.	...	...	...	*
Pyrula reticulata, Linn.	*	*	*	*
Cassis Saburon, Brug.	...	*		
Buccinopsis Dalei, Sow.	*	*	*	
Murex scalariformis, Nyst	...	*	...	*
Trophon consocialis, S. V. W.	...	*	*	*
Fusus gracilis, Da Costa	...	...	*	
Pleurotoma crassa, A. Bell	...	...	*	*
Conus Dujardinii, Desh.	*	*	...	*
Pleurotoma inermis, Part.	...	*	*	?
„ *intorta*, Broc. / „ var. *plicatilis*, Nyst	...	*	...	?
Aporrhais pes-pelicani, Linn.	*	*	*	
Turritella incrassata, Sow.	...	*	*	
Natica millepunctata, Lam.	*	*	*	
„ *varians*, Duj.	*	*	*	*

[1] Prestwich believed that the Lenham Beds had been upheaved prior to the deposition of the Coralline Crag, Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 134. See also A. Bell, Geol. Mag. 1872, p. 209.

List of Diestien Mollusca (*continued*).

	Lenham or Box-stones.	Miocene or Ital. Pliocene.	Cor. Crag.	Extinct.
Trochus obconicus, S. V. W.	...	...	*	*
„ *zizyphinus*, Linn.	*	*	*	
„ *multigranus*, S. V. W.	...	...	*	*
Margarita maculata, S. V. W.	...	*	*	*
Calyptræa chinensis, Linn.	...	*	*	
Ringicula buccinea, Broc.	...	*	*	
Bulla cylindracea, Penn.	...	*	*	
Scaphander lignarius, Linn.	*	*	*	
Dentalium dentalis, Linn.	*	*	*	
Ostrea princeps, Sow.	*	...	*	*
Pecten grandis, Sow.	...	...	*	*
„ *tigrinus*, Müll.	...	*	*	
„ *pusio*, Linn.	...	*	*	
„ *opercularis*, Linn.	*	*	*	
Lima Loscombii, G. B. Sow.	?	*	*	
Modiola phaseolina, Phil.	...	*	*	
„ *sericea*, Brongn.	...	*	*	*
Pectunculus glycimeris, Linn.	*	*	*	
Limopsis aurita, Broc.	...	*	*	
Nucula lævigata, Sow.	...	*	*	*
Leda semistriata, S. V. W.	?	...	*	*
Lucina borealis, Linn.	...	*	*	
Diplodonta astartea, Nyst	?	*	*	
Cardita scalaris, Leathes	...	*	*	
„ *chamæformis*, S. V. W.	...	...	*	*
„ *orbicularis*, Leathes	...	*	*	*
Cardium decorticatum, S. V. W.	*	...	*	*
Astarte Basterotii, Laj.	*	...	*	*
„ *corbuloides*, Laj.	...	...	...	*
„ *incerta*, S. V. W.	...	...	*	*
„ *Omalii*, Laj.	*	*	*	*
„ *sulcata*, Da Costa	...	*		
Cyprina islandica, Linn.	*	*	*	
„ *rustica*, Sow.	*	*	*	*
Isocardia cor, Linn.	*	*	*	
Venus casina, Linn.	...	*	*	
„ *ovata*, Penn.	...	*	*	
„ *imbricata*, Sow.	...	...	*	*
Cytherea Chione, Linn.	*	*	*	
Donax politus, Poli	*	...	*	
Tellina Benedenii, Nyst	*	?	...	*
Abra prismatica, Mont.	...	*	*	
Mactra solida, Linn.	...	...	*	
„ *arcuata*, Sow.	*	...	*	*
Cultellus tenuis, Phil.	...	...	*	*
Solen ensis, Linn.	*	*	*	
Thracia inflata, Sow.	...	...	*	*
Corbula striata, W. & B.	...	*	*	
Panopæa Faujasii, M. de la G.	*	*	*	
Glycimeris angusta, Nyst	*	*	*	*
Teredo norvegica, Speng.	?	*	*	
Saxicava rugosa, Linn.	...	*	*	
Terebratula grandis, Blum.	*	*	*	*
Lingula Dumortieri, Nyst	...	...	*	*

The fauna of this zone resembles generally that of the Coralline Crag, but it contains a few Miocene species not known from, or rare in, that formation, such as *Pyrula reticulata*,[1] *Cassis Saburon*, *Murex scalariformis*, *Conus Dujardinii*, and *Pleurotoma intorta*. On the whole, it presents a somewhat more recent facies than that of Lenham, although it seems older than the Coralline Crag.

M. Van den Broeck has, however, discovered a fossiliferous bed at Waenrode, near Diest, from which the following species have been obtained :—

	Extinct	Cor. Crag or Diestien	Lenham or Box-stones	Miocene
Cassis Saburon, Brug.	...	*	...	*
† „ *Rondettii* (?) Bast.	*	...	...	*
Pyrula reticulata, Sism.	*	*	*	*
Aporrhais pes-pelicani, Linn.	...	*	*	*
Turritella incrassata, Sow.	...	*	*	*
Scaphander lignarius (?) Linn.	...	*	*	*
†*Pecten Caillaudi* (?) Nyst	*	...	...	*
Nucula lævigata, Sow.	*	*	...	*
Leda semistriata, S. V. W.	*	*	?	
Cardium subturgidum, d'Orb.	*	...	...	*
Lucina borealis, Linn.	...	*	...	*
† „ *Drouetti* (?) Nyst	*	...	...	*
Cryptodon flexuosum, Mont.	...	*	...	*
Isocardia lunulata, Nyst	*	...	*	*
Cytherea rudis (?) Poli	...	*	...	*
Tellina compressa, Broc.	...	*	...	*
Abra prismatica, Mont.	...	*	...	*
Cultellus tenuis, Phil.	*	*		
Corbula striata, W. & B.	...	*	...	*
Teredo, sp.				

If it were not for the presence of the three species marked †, the identification of which seems to be uncertain, this group of fossils would be as nearly related to the Pliocene as to the Miocene. Out of the 19 species named, 14 occur also in the Coralline Crag and the Diestien, and 16 in the Miocene of Belgium; but there are 3, *Leda semistriata*, *Tellina compressa*, and *Cultellus tenuis*, that are not known from the last-named formation. If we omit the doubtful species, the proportion is 13 out of 14 in the former case, and 11 out of 14 in the latter. The percentage of Coralline Crag forms generally in the Belgian Miocene is very different. M. Van den Broeck enumerates 175 species of mollusca from the Miocene zone à *Panopæa Menardi*, only 79 (or 45 %) of which are found in the Coralline Crag, and 143 from the zone à *Pectunculus pilosus*,[2] only 77 (or 53 %) of which are common to that deposit. The list

[1] *Pyrula reticulata* and *Pleurotoma intorta* are, however, found also in the zone à *Isocardia cor*.

[2] 'Esquisse Géol. & Paléont. des Dépôts Plioc. d'Anvers,' 1876, pp. 42 & 56.

of shells from Waenrode is very short, and it may not be truly representative. So far as the evidence goes, however, the fauna does not seem to me typically Miocene, though Belgian geologists believe, on stratigraphical grounds, that it is at the latest of Miocene age.[1] Without expressing, therefore, any decided opinion on the subject, I merely call attention to this interesting discovery of a bed which, like that of Lenham, contains a fauna closely resembling at the same time those of the Coralline Crag and of the Belgian Miocene.

Tabulating these results, we have:—

	Extinct forms	Coralline Crag
Waenrode	42 %	68 %
Diestien beds.		
Zone à *Terebratula grandis*	46 %	85 %
Lenham	43 %	77 %
Belgian Miocene.		
Zone à *Pectunculus pilosus*	53 %	54 %
,, *Panopæa Menardi*	59 %	45 %

III. The Coralline Crag.

As is well known, the Coralline Crag occurs: (*a*) at Tattingstone, 4 miles south of Ipswich, limited there probably to a very small area, and exposed in one section only[2]; (*b*) at Ramsholt and Sutton, on the eastern bank of the Deben estuary, where it may be traced, though not continuously, for rather more than ½ mile; and (*c*) in the main mass of the formation, extending from Boyton and Gedgrave to Iken and Aldeburgh (Butley Creek and the river Alde intervening), and thence to some submarine rocks off the coast at Sizewell, 5 or 6 miles N.N.E. of the last-named locality. Traces of it are said to have been found at Trimley (*teste* Acton)[3] and at Waldringfield (Whitaker),[4] and possibly it may exist elsewhere under the high land between the Orwell and the Deben, or between the latter river and Butley Creek. Along the low land fringing those rivers, however, no Coralline Crag is known, the Red Crag being shown in many places to rest directly on the London Clay, as it does also along the coast from Walton-on-the-Naze to Bawdsey.

The method adopted by Prestwich was to take the beds present in the small outlier at Sutton (which he described at some length) as typical of the formation generally, but he did not attempt to show, either by stratigraphical or palæontological evidence, that the divisions observed at Sutton are constant over the whole area,

[1] M. Van den Broeck was at first inclined to think that the Waenrode deposit was Pliocene, Ann. Soc. Roy. Malacol. Belg. vol. xix (1884) p. lvi.

[2] [I understand that a second exposure of Coralline Crag has recently been discovered at Tattingstone.—June, 1898.]

[3] Suppl. 'Crag Mollusca,' Introd. p. iii, Monogr. Palæont. Soc. 1872.

[4] Mem. Geol. Surv. 1885, Ipswich, p. 65.

nor do I think that it is possible to do so; he stated, however, but as a matter of opinion only, the horizons to which he considered the beds occurring at other localities should be referred. He claimed that these supposed zones are characterized by distinctive groups of fossils, and that their deposition was attended by great physiographical changes, including a submergence of the Crag basin, by which at one stage the North Sea attained a depth of from 500 to 1000 feet, while at another the climate of Northern Europe was refrigerated sufficiently to permit of floating ice reaching East Anglia, with boulders from either Scandinavia or the Ardennes.

The Coralline Crag, both in the Sutton outlier and in the main mass of the formation, seems to fall naturally into two divisions (a view held by all observers up to the present time), the lower consisting of shelly incoherent sands, generally of a whitish colour, and the upper of a porous ferruginous limestone, soft and friable when first quarried, but acquiring a hard crust by exposure to the air.[1] The colour of the latter, normally a light ochreous yellow, assumes on further oxidation a dark rusty hue. Specimens of *Pecten* and other mollusca whose shells are composed of carbonate of lime in the form of calcite (the translucent variety), and the remains of polyzoa, are common in this rock-bed, as they are also in the shelly sands, but the opaque or arragonite mollusca are represented in it by casts only.[2] These casts occur, however, in many places and at different levels, generally in layers, and often in great abundance.

At first sight nothing could well seem more distinct than the soft shelly beds of the lower, and the hard ferruginous rock of the upper part of the Crag, but I now believe that the difference is more apparent than real, and that the rock-bed is merely an altered condition of the shelly sands,[3] its ferruginous character being due to the infiltration of water charged with oxide of iron, arising from the decomposition of part of the glauconite of the unaltered Crag. Indeed, I have lately discovered, in an important section at Iken, which will be described later on (see pp. 338, 339), the two kinds of Crag side by side, and passing into each other.

Prestwich separated from the rest the upper or ferruginous portion of the Crag, which, as will be seen by the sections (figs. 5 & 7, pp. 328 & 332), forms nearly one half of the entire mass of the formation, calling it zones G & H. The nodule-bed at the base of the Crag, found in one spot only at Sutton, he described as

[1] It sometimes becomes sufficiently hard to be used for building, as for example in the tower of Chillesford Church.

[2] See P. F. Kendall, Geol. Mag. 1883, p. 497.

[3] More than 20 years ago attention was simultaneously called by Mr. Whitaker, and by Mr. Wood & myself (Quart. Journ. Geol. Soc. vol. xxxiii, 1877, pp. 75 & 122), to the alteration of the Red Crag by infiltration; and M. Van den Broeck, about the same time, made similar observations in Belgium. It is not a little strange that it occurred to none of us that the Coralline Crag might have been affected in the same way.

zone A,[1] dividing the shelly sands between A and G, which have in all a maximum thickness of no more than 30 feet, into five zones: B, C, D, E, and F. Whether we examine it chemically or microscopically, however, we can find no essential difference in the material of which these several beds, B to F, are composed. It is throughout mainly of organic origin, consisting of the comminuted shells of marine organisms or of calcareous matter derived from their decomposition, with only a small admixture of inorganic ingredients. The proportion of the latter varies slightly in specimens taken at different spots, as will be seen below.

Mr. Francis Sutton, of Norwich, a well-known authority, has kindly analysed for me some examples of the two varieties of Crag, with the following result:—

	Carbonate of Lime	Silica	Oxide of Iron and Alumina
Shelly sands (No. 1)	78·62 %	7·75 %	3·50 %
Ferruginous Crag (No. 2)	78·95 %	11·50 %	7·20 %

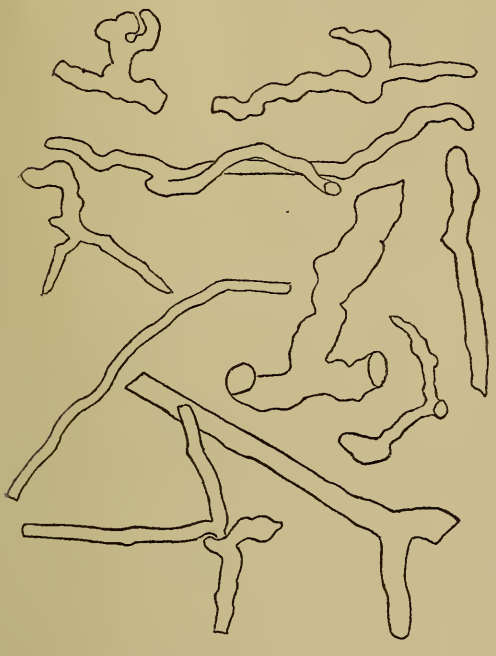
More recently his son, Mr. W. Lincolne Sutton, the public analyst to the Corporation of Norwich, has tested some fresh samples, and reports as follows:—

	Carbonate of Lime	Silica	Oxide of Iron and Alumina
Shelly sands (No. 3)	70·9 %	13·5 %	7·1 %
„ „ (No. 4)	74·7 %	12·8 %	5·5 %
Ferruginous Crag (No. 5)	79·2 %	11·4 %	4·2 %

Dr. G. J. Hinde, F.R.S., has been good enough to examine samples 3 & 5 for me microscopically, and says: 'Under a low power or with a hand-lens the Crag is seen to contain, as is well known, specimens of foraminifera and entomostraca, fragments of mollusca and polyzoa, and the spines of echinoderms, with grains of quartz, some angular, others rounded, and dark green granules of glauconite, rounded and polished. Among the finer material I find an immense number of minute almond- or diamond-shaped calcspar-crystals, amorphous particles, and coccoliths, and numerous rod-like bodies, simple or branching, usually vermiform' (see fig. 2); these he considers may be 'the solid infillings, by a silicate of iron, of borings in molluscan shells by the action of organisms supposed to be of the nature of algæ or fungi. They are not seen until the shells have been dissolved by acid, are translucent, and polarize feebly. Numerous coccoliths are present, somewhat larger than those in the Upper Chalk, and I do not think that they have been derived from that formation. It is important to notice that only two microscopic chips of flint were observed, with perhaps an occasional flake of mica and a grain of felspar.'

[1] The basement-bed, zone A of Prestwich, is, of course, of a different character, originating under conditions dissimilar to those of the rest of the Crag.

Fig. 2.—*Rod-like bodies in Coralline Crag residues* (*after solution in hydrochloric acid*).



×100 diameters.

In some borings at Gedgrave and Sudbourne, to be described hereafter, I found at the base of the formation a bed, 12 inches or so thick, resting on the London Clay, which it resembles in colour, consisting of blue Crag which differs from the shelly sands in containing a larger proportion of quartz-grains. Analysed, it was proved to contain:—

	Carbonate of Lime	Silica	Alumina and Oxide of Iron
No. 6	57·30 %	35·10 %	3·80 %

the iron being mainly in the unoxidized or ferrous state.

Dr. Hinde observed in this blue Crag 'numerous grains of a translucent mineral, probably a silicate of iron, allied to glauconite; they are mostly subangular, and polarize feebly between crossed nicols.' No polyzoa were noticed, but this absence may be accidental, as Prestwich found them at the base of the Crag at Sutton.

The consolidation of the ferruginous Crag and the dissolution of the arragonite-shells seem to have taken place at a comparatively remote period, that is, previously to the deposition of the Red Crag, as both Sir Joseph Prestwich[1] and Mr. P. F. Kendall[2] found blocks of the former in the latter deposit; but the Coralline Crag has also been subjected to the action of acidulated water in more recent times. Mr. Sutton has analysed some dark red earth from the cylindrical pipes, familiar to all students, which penetrate the Crag from the surface downward, often to a considerable depth, and finds that it contains the merest trace of calcium carbonate, as will be seen from the following analysis:—

	Carbonate of Lime	Silica	Oxide of Iron	Alumina
No. 7	0·56 %	74·20 %	11·40 %	2·10 %

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 341.
[2] Geol. Mag. 1883, p. 499.

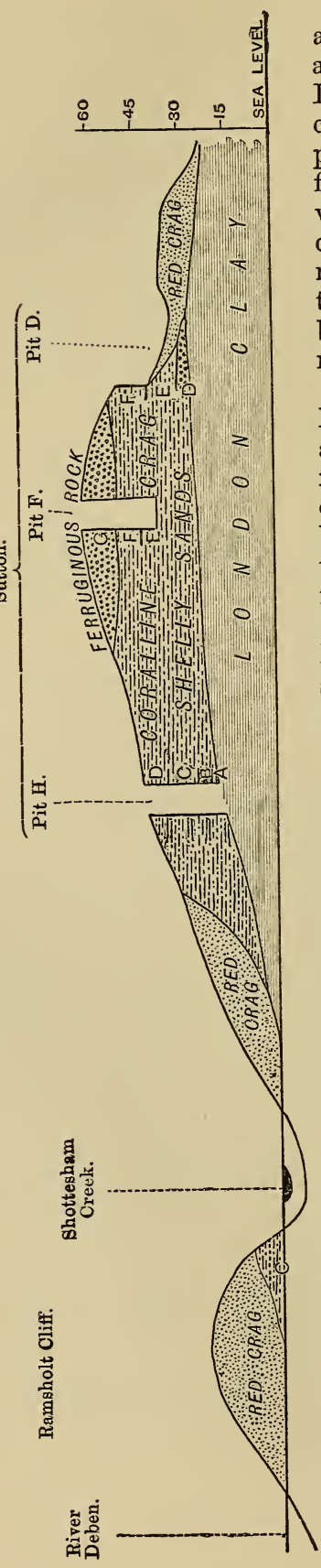


Fig. 3.—*Section showing the irregular surface of the London Clay under the Coralline Crag at Ramsholt and Sutton, and the want of stratigraphical accordance between the supposed zones of the latter at those localities.*

The Coralline Crag of Ramsholt and Sutton occupies one side of an old channel or depression in the London Clay, which at that point coincides to some extent with the present estuary of the Deben (see fig. 3). At Ramsholt the Crag was formerly exposed in a low cliff close to the river, but it is not now visible; its junction with the London Clay there was probably little, if at all, above Ordnance datum.

Prestwich regarded the Ramsholt bed as belonging to his zone C, and he gave a list of 17 species of mollusca from it, besides echinodermata, etc., some of which he believed to be more abundant there than elsewhere. Most of the mollusca, however, are common everywhere in the formation, and I do not think that generally the species mentioned can be looked upon as more characteristic of one portion of it than of another.

At Sutton, a short distance ($\frac{1}{3}$ mile) from Ramsholt Cliff, there was formerly a pit (H of Prestwich's section) at which the nodule-bed (zone A) was observed by himself and Prof. Ray Lankester. At that spot the Crag is, I believe, at a higher level than that of Ramsholt, resting on the London Clay 8 feet above high-water mark (see fig. 3).[1] Prestwich, however, called the beds there exposed zones A, B, & C.

At his pit D, 500 yards north-east of the last, where the London Clay rises 12 feet higher, he classed the beds as zones D, E, & F, while at pit F, 250 yards distant, he considered them to belong to zones E, F, & G. It will be seen by reference to fig. 3 that, taking the dip into account, in

[1] The measurements in Prestwich's paper and sections are somewhat difficult to follow. Some are taken above high-, some above low-water mark of the River Deben, and some, possibly, above Ordnance datum.

no two of these four sections are the supposed zones in the same relative position, nor is any reason suggested, except that the London Clay floor was uneven,[1] why no beds representing periods B & C should have been deposited in the locality of pit D. The gradient of the surface of the London Clay between pits H and D is, however, only about 1 in 100, so that this explanation seems inadequate.

Prestwich cited the following genera as specially characteristic of certain zones in the Sutton Crag, namely:—*Cyprina*, *Pecten*, *Mya*, *Cardita*, *Astarte*, *Anomia*, and *Venus*; but these are met with not only in all parts of the Coralline, but also and abundantly in every portion of the succeeding Red Crag formation. Mr. Burrows, one of the authors of the great work on the Foraminifera of the Crag, just completed,[2] speaks of a band containing *Cyprina islandica* as apparently constant to zone D, and he names a dozen other species of mollusca, smaller forms, which he considers peculiar to Prestwich's zone F, or more abundant in it at Sutton and Gedgrave than at any other horizon. *Cyprina islandica* has, however, existed in the North Sea, probably without intermission, from the Miocene period to the present day, so that its presence or absence at any one spot in the Crag must be accidental; and it does not seem to me that the other species named by him can be regarded as characteristic even of the whole of the Coralline Crag, still less of any special zone in it. With one or two exceptions, they are Miocene forms, which continued to exist, and even to abound in the Crag area during the subsequent period represented by the Walton bed and the Scaldisien of Belgium, some of them being still found in British seas. It would, however, be equally possible to make up a list of shells which are common at Sutton, and rare or unknown at Gedgrave, or *vice versâ*, but it is a constant feature of the shelly sands that some localities yield a more varied or a somewhat different fauna as compared with others.

Any resemblance, moreover, which the molluscan fauna of the beds regarded by Prestwich as zone F at Sutton may bear to those of Gedgrave Hall seems to me to be antagonistic to, rather than in favour of, his views, since the shelly seam at the latter place is within 15 feet of the base of the formation, which at Sudbourne, in the immediate neighbourhood, is 60 feet in thickness. Stratigraphically, therefore, the Gedgrave shell-beds belong to a lower part of the Crag rather than to the supposed upper zone F, to which they have been assigned.

The evidence upon which I rely for the separation of the Lenham Beds from the Coralline Crag, or which I propose to offer in favour of zones of the Red Crag, is, I submit, of an essentially different character. We find at Lenham Miocene forms which, so far as the evidence goes, had ceased to exist in the Anglo-Belgian basin before the deposition of the Coralline Crag, and have never since reappeared; while the older Red Crag deposits contain southern and extinct species, which gradually became less abundant in the

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 116.

[2] Monogr. Palæont. Soc. 1866–97; see also Geol. Mag. 1895, p. 511.

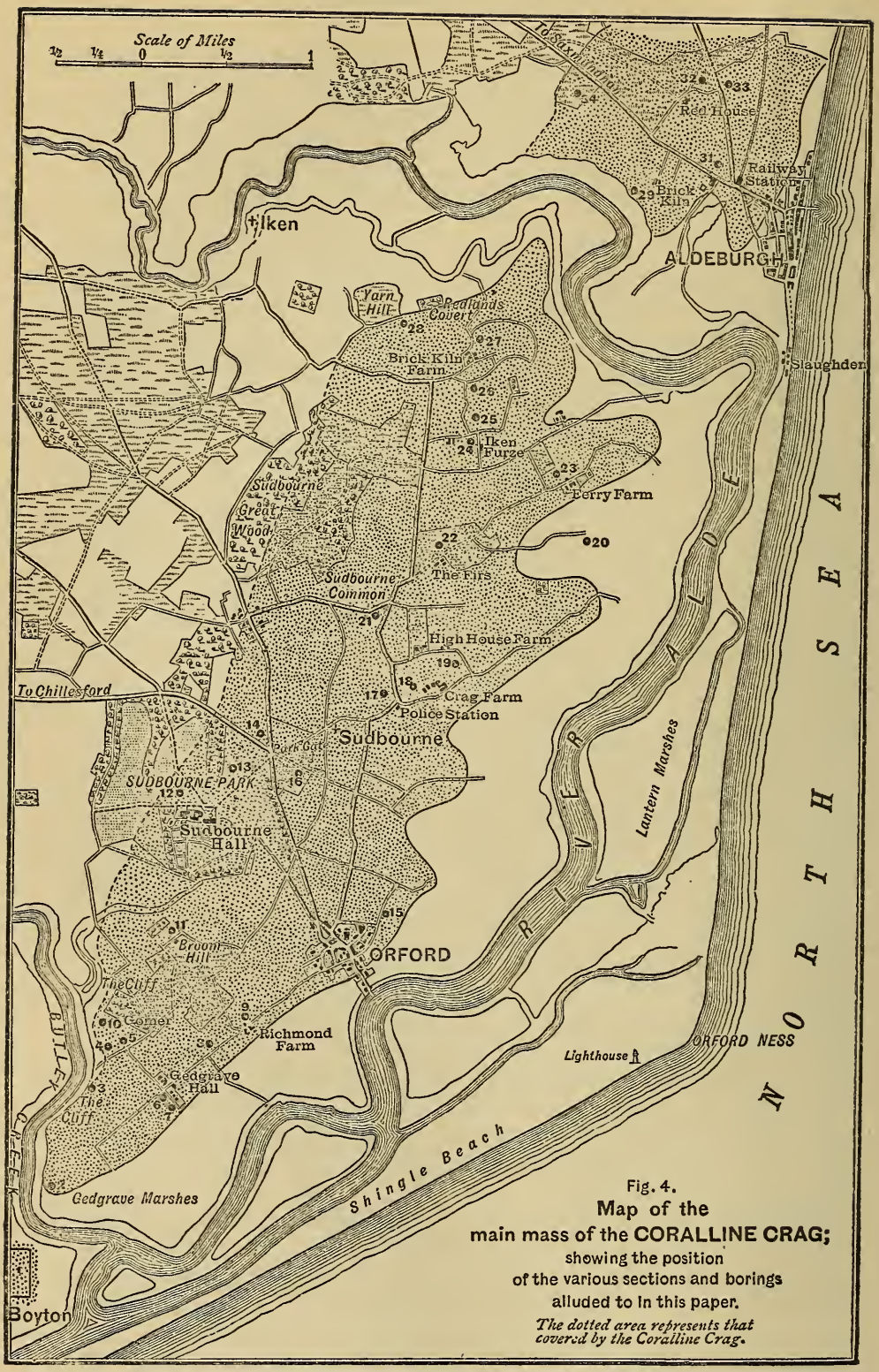


Fig. 4.
Map of the main mass of the CORALLINE CRAG;
showing the position of the various sections and borings alluded to in this paper.
The dotted area represents that covered by the Coralline Crag.

Note.—The position of pit 30 should have been indicated just below the letter K (in 'Kiln'), due west of Aldeburgh.

North Sea area, and finally died out altogether, their place being taken in the newer beds by arctic and boreal forms, unknown from the older formation.

The principal difference between the various portions of the lower or unaltered condition of the Coralline Crag seems to be that in some the mollusca are chiefly of large, in others of smaller species, a third variety of Crag being composed of comminuted material only. Certain localities, however, as for example the Gomer pit, are characterized by an abundance of univalves, which generally are much less common than bivalves in these beds, but such differences are by no means persistent. Layers of large shells, containing especially *Cyprina islandica*, occur in all parts and at all levels in the Crag, as will be seen hereafter, and I am unable to find any bed which is continuous except for a short distance, nor is this to be wondered at. It is not probable that at any one period the sea-bottom was for some miles continuously covered with a thin layer of the dead and drifted valves of *Cyprina* and other large molluscs, and that then these species disappeared for a time from the Crag area. Shells are sorted out by currents of varying strength, just as pebbles are in beds of gravel, small specimens naturally accumulating in one place, larger ones in another, and comminuted shells or fine calcareous sand in a third.[1]

There are localities in the Crag, however, at which it seems at first sight that beds, the fossils of which are more or less of a similar character, may be traced continuously from one section to another, as, for example, between the Broom pit at Gedgrave (No. 11 of map, fig. 4) and the Hall pit (No. 12) in Sudbourne Park. At each of these we find one seam with *Cyprina* and other large molluscs, and another seam immediately over it containing principally smaller shells, both being on about the same level at the two places. To an observer who believes, as Prestwich did, that the Crag rests on the more or less horizontal surface of the London Clay,[2] these would seem to be the same, but between the two pits the base of the Crag dips 8 or 9 feet (see fig. 5, p. 328), and thus beds which appear to be in correspondence are not really so.

I have attempted, from the notes given in Prestwich's memoir, to construct a diagram (fig. 6, p. 329) showing the structure of the Coralline Crag from Ramsholt to Aldeburgh according to his views, but the result does not seem to me to lend much support to the zone-theory.

In the table on pp. 330–1 are enumerated the features upon which Prestwich relied to justify the separation of the Coralline Crag into

[1] In the Natural History Museum at South Kensington there is a large block of limestone from the Calcaire grossier, similar in character to the shelly sands of the Coralline Crag, containing in profusion the drifted and stratified shells of mollusca, which are more or less of the same size throughout, and but few univalves. Both univalves and larger bivalves were present in the seas of that period, as may be seen by reference to one of the wall-cases close by. None, however, were deposited at the spot from which this block was taken, the selective power of the currents which there prevailed having sorted out only forms of a certain size and weight.

[2] See his section from Sutton to Iken, Quart. Journ. Geol. Soc. vol. xxvii (1871) pl. xx.

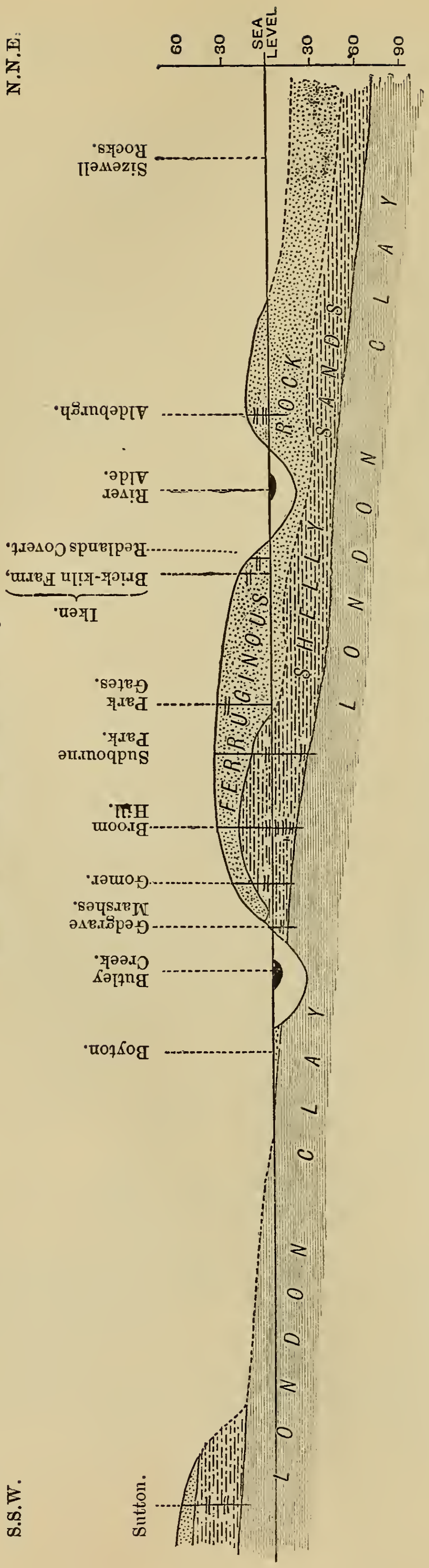


Fig. 5.—Section showing the structure of the Coralline Crag (according to the present writer) and its progressive dip N.N.E. of its junction with the London Clay.

[The thick straight bars = indicate the position of the seams of large shells. The more recent beds are omitted.]

the eight zones proposed by him, together with my remarks thereon. It will be seen that many of the characteristics which he considered distinctive of certain parts of the formation only are of the most general character and are equally applicable to others; but even if this were not so, slight lithological differences are hardly a satisfactory test of age, unless they can be traced stratigraphically. The sediment now accumulating at the bottom of the North Sea is not everywhere the same.

Mr. Burrows, in the Geol. Mag. paper before alluded to, claims the evidence of the foraminifera as being in favour of the zone-theory. I differ from that gentleman with much regret, but I cannot think that the facts he recites are conclusive. In his paper, and in the monograph by himself and his coadjutors, certain species of foraminifera are stated to be specially characteristic of zones D, E, F, & G at Tattingstone, Sudbourne, Gedgrave, and Aldeburgh,[1] but on referring to the list published by him [2] it will

[1] No evidence is offered as to zones A, B, C, or H.

[2] 'Crag Foram.,' Monogr. Palæont. Soc. 1897, p. 374.

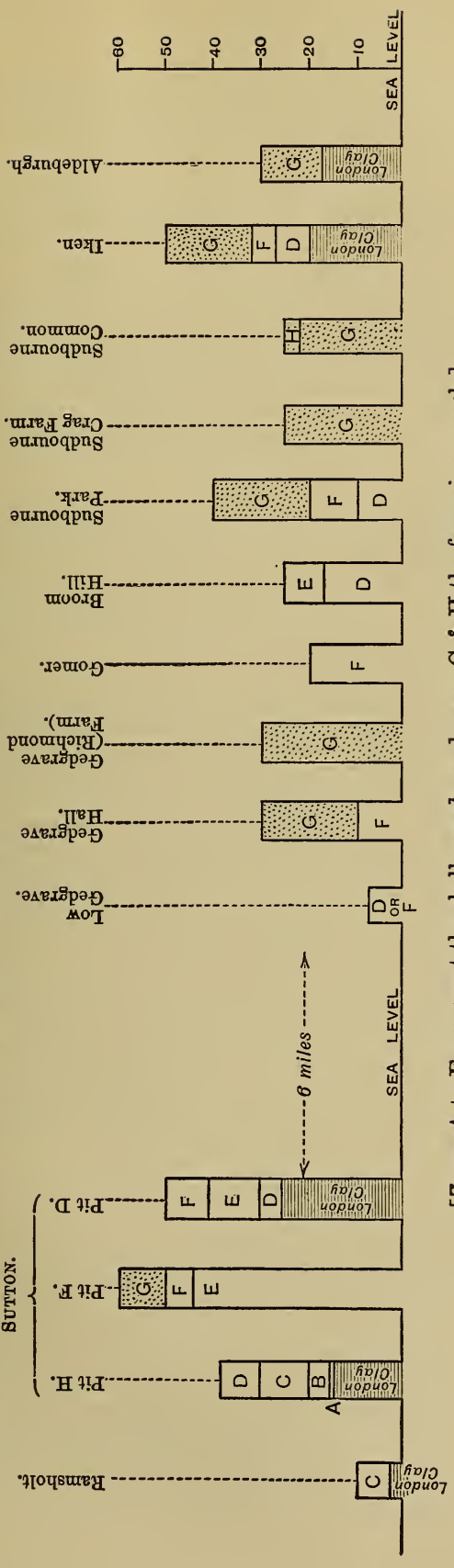


Fig. 6.—*Diagram showing the comparative positions of the supposed zones in the Coralline Crag, according to Prestwich.*

[Zones A to F represent the shelly sands, and zones G & H the ferruginous rock.]

be seen that none of these are confined to any one zone, most of them being common at one locality in what he regards as zone D, at another in E, and in F or G at a third or fourth. On the contrary, it is sometimes the case that forms are common at one spot and rare at another in beds considered by Mr. Burrows to belong to the same zone. Even if this were not so, I cannot think that the evidence of the foraminifera is of great value. Most of the forms in question are still living, and they have a world-wide distribution, being found in all seas and at all depths. Of one, *Miliolina seminulum*, the authors of the Palæont. Soc. monograph say, 'Scarcely a sample of sea-sand, either dredged or littoral, from any quarter of the globe, can be examined without finding specimens of it.'[1] Moreover, the foraminifera are not generally so distinctive of special formations as are the mollusca, having a wide range in time as well as in space; the Crag species, with one or two exceptions, are recent forms, going back also to early Tertiary, and some of them even to the Mesozoic or Palæozoic epochs.

[1] *Op. cit.* p. 10 (1866).

Table showing, according to Prestwich, the features characteristic of the various zones into which he proposed to divide the Coralline Crag.

		Remarks.
A.	Bed, 1 to 1¼ foot thick, containing phosphatic nodules, mammalian remains, and derivative fossils and boulders.	Apparently confined to one district in which a similar bed occurs at the base of the Red Crag. A few phosphatic nodules only, but no boulders, were found at the base of the Coralline Crag in borings at Gedgrave and Sudbourne.
B.	Comminuted shells, with *Turritella*, and single valves of *Cyprina*, *Pecten*, *Mactra*, etc.	This bed, 4 feet only in thickness, was observed by Prestwich at one spot only at Sutton. The features mentioned are equally applicable to other parts of the formation.
C.	Light-coloured marly Crag, abounding in large shells, *Mya* and *Cyprina* (sometimes double), *Anomia*, *Diplodonta*, *Astarte*, and *Venus*.	At one spot only at Sutton. The species of mollusca named are among the commonest forms of both the Coralline and Red Crags.
		With the exception of *Cyprina*, which is common everywhere, the species enumerated by Prestwich (*op. cit.* p. 115) as characteristic of zone C at Ramsholt differ entirely from those here named from Sutton.
	Foraminifera abundant. Univalves scarce.	The authors of 'The Foraminifera of the Crag' state (*op. cit.* pp. 374, etc.) that these organisms are more or less abundant in every part of the formation. Univalves are also scarce at localities regarded by Prestwich as belonging to other zones.
D.	Comminuted shells, large entire or double shells. Bands of limestone in upper part.	Features common to other parts of the Crag. Found in borings at Gedgrave at one spot only.
E.	Sand with numerous polyzoa, often in the position of growth, and *Echini*.	Common features of the polyzoan rock-bed, regarded by Prestwich as zone G, at Sudbourne, Iken, and Aldeburgh. The spines of echinodermata occur at all levels.

Table (*continued*).

		Remarks.
F.	Sand with numerous small entire shells and seams of comminuted shells.	Features common to all parts of the unaltered Crag.
G.	Comminuted shells with remains of polyzoa, forming a soft building-stone. False stratification and oblique bedding are constant characters.	Indurated character of polyzoan rock due to infiltration, and not peculiar to the upper part of the Crag. False bedding not confined to the upper part of the formation.[1]
H.	Sand and comminuted shells.	Possibly an atmospherically-altered condition of the surface of the indurated Crag.

The term 'zone' is, I submit, rightly used for a deposit clearly marked out from others, either by the general character of its fauna, or because it represents some important physiographical change in the conditions of any period; but it conveys a wrong impression when employed for such minor divisions as those of the Coralline Crag, even if they could be shown to be persistent throughout the formation. It may be safely asserted, I think, that no evidence has been adduced to show that any one of the alleged zones is characterized by the presence of species which did not also exist at earlier or later periods in the seas of the North of Europe, and which were evidently then appearing for the first time, or disappearing from the Anglo-Belgian basin.

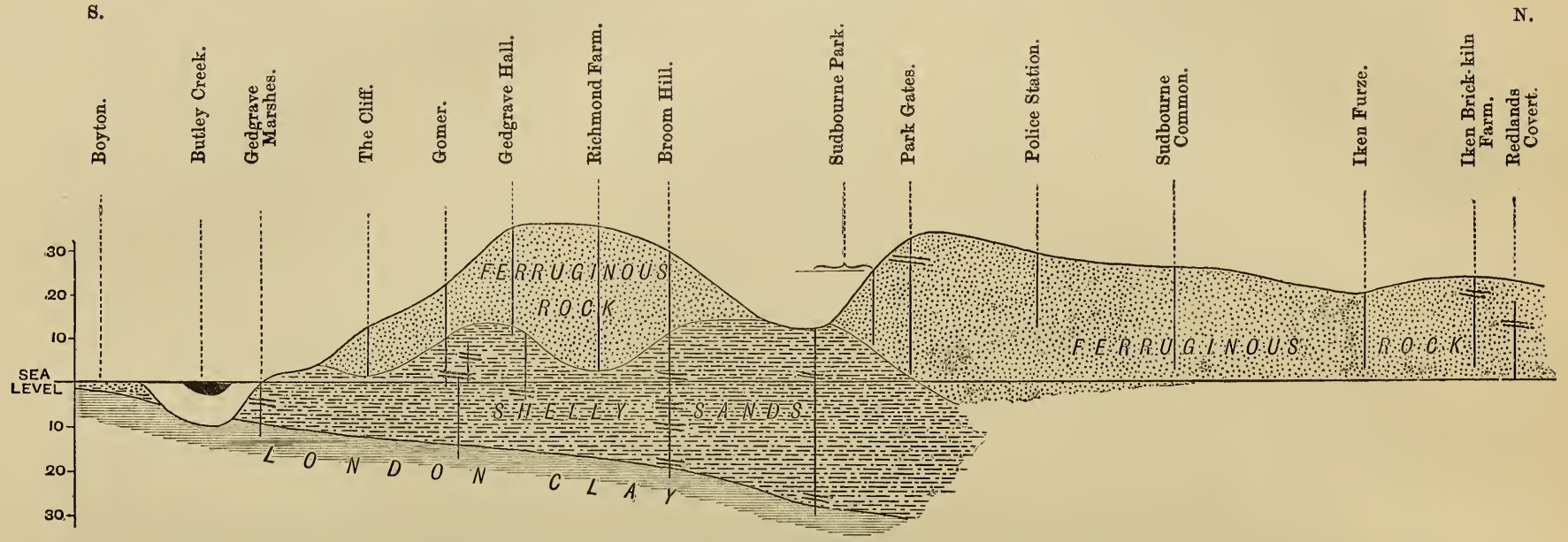
As the base of the Coralline Crag had been reached at one locality alone, namely, in the Sutton district, it seemed to be of some importance to ascertain by boring not only the total thickness of the formation where it is best represented (that is, in the neighbourhood of Orford), but to acquire some knowledge, if possible, of any lower beds which might be present there.

The apparatus that I used for boring was, with some modifications suggested by my early failures, that designed by MM. Van den Broeck & Rutot, and described by them in a paper published by the Société Belge de Géologie.[2] It is admirably adapted for rapidly penetrating beds of dry and moderately coherent material. The only part of the Coralline Crag, however, which it is necessary to explore in this way lies below the water-line, the upper part of the Crag

[1] Mr. Clement Reid considers that the whole of the Coralline Crag is 'more or less current-bedded,' Mem. Geol. Surv. 1890, 'Plioc. Deposits of Britain,' p. 36.

[2] Bull. Soc. Belge de Géol. vol. ii (1888) p. 135.

Fig. 7.—*Sections and borings in the Coralline Crag between Boyton and Iken, showing the irregularity of the divisions between the ferruginous rock-bed and the unaltered shelly sands.*



[Seams of large shells shown by thick bars =. Newer beds omitted.]

being sufficiently shown by numerous sections; but the difficulty of boring through loose and wet sand is very great, and requires much patience, especially when a depth of 15 or 20 feet is reached.[1]

The different borings made in the neighbourhood of Orford show that the junction between the London Clay and the Coralline Crag has an average dip, in a northerly or north-easterly direction between Butley Creek at Gedgrave and Sudbourne Hall, of 8 feet to the mile; beyond the latter place it lies too deep to be reached by my apparatus.[2] The gradient between Sutton and Gedgrave is about 6 feet per mile (see fig. 5, p. 328), and between Sutton and Tattingstone rather less. At the last-named locality the Crag-beds approach the 100-foot contour-line, but occur somewhat below it. At Sutton, as we have seen, they rest upon the London Clay at 20 feet above high-water mark, and they are there about 40 feet thick in vertical section.

Tracing the Coralline Crag from Sutton towards the north-east, it is found at Boyton occurring slightly below the level of the marsh, but at present it is not accessible there—unfortunately so, as some species were obtained in abundance at Boyton which are not common at Gedgrave and Sutton. Both the Coralline and Red Crags and the nodule-bed also are present there, and it may be possible hereafter, by boring, to clear up the question of the true position of the last-named deposit. So far as one can judge from the available evidence, the nodule-bed formerly exposed at this locality is below the Coralline Crag.[3] The shells obtained by the coprolite-diggers were so mixed that it was impossible to say certainly from which formation they had been derived. Some geologists have suggested, but I think without sufficient evidence, that at Boyton there is a Red Crag fauna of a special and distinct character. I visited the locality in 1897: no section was then visible, but on the site of one of the old workings there was a heap of soil, and from it I picked out a few specimens or fragments of the following (all of them being later Red Crag forms, and of the usual Red Crag colour):—

Purpura lapillus.
Buccinum undatum.
Trophon antiquus.
,, *contrarius.*
Turritella incrassata.
Pecten opercularis.
Cardium edule.
,, *grœnlandicum.*
,, *Parkinsoni.*
Cardita senilis.
Astarte Omalii.
Cyprina islandica.
Tellina obliqua.
,, *crassa.*
,, *prætenuis.*
Mactra solida.
,, *ovalis.*
,, *elliptica.*
Mya arenaria.
,, *truncata.*

[1] If some light and portable apparatus could be devised, suitable for boring through wet and sandy soil, it would be of great value to amateur geologists.

[2] The greatest depth attained by me was 31 feet.

[3] See also Whitaker, Mem. Geol. Surv. 1886, Aldborough, p. 9. On one of Mr. Wood's survey-maps is the following note:—'This rectangular mark [shown also in fig. 4, p. 326, of the present paper] is that which Mr. Robert Bell has drawn in a copy-map sent to me, to represent the coprolite-trench from which so many shells are obtained. He says there is about 18 inches of Coralline, overlain by 30 inches of Red Crag and sand.'

I believe that most of the Boyton specimens to be found in our Museums have come from the Coralline Crag, and that the Red Crag of that neighbourhood belongs to the Butley zone. Sometimes, however, the Coralline Crag shells have been discoloured by infiltration from the immediately overlying Red Crag.

On the east side of Butley Creek, at several points in the parish of Gedgrave, and near the edge of the marsh, the London Clay was reached by boring through the Coralline Crag at depths of 9, 12, and 13 feet respectively. A few small phosphatic nodules occurred everywhere near the base of the Crag, but neither in any of the borings at that place nor elsewhere did we meet with derivative fossils or large stones, such as those found in the basement-bed at Sutton. At one of these borings (No. 2 in fig. 4) we found, at a depth of 6 feet, fragments of *Cyprina*, *Astarte*, etc., and lower down some small shells. At another (No. 4) the Crag was very shelly, containing *Astarte Burtinii* and *Turritella incrassata*, no large forms being observed. At another spot (No. 5), on higher ground, but within a few yards of the last, large species, as for example *Cyprina* and *Venus*, were abundant, the borer grinding through them for 4 or 5 feet. The well-known pit in the Gomer field (No. 10) is now ploughed up; from it were formerly obtained, at about the same level as that of boring No. 5, a large variety of species, including many univalves (see the list published by Prestwich[1]), which are almost unknown from the other pits in the neighbourhood.[2] But I may mention, as illustrating the want of correspondence between these shelly bands, that Mr. Buckingham, the veteran collector at Orford, has made a number of attempts during the last few years to find a new exposure of the old Gomer bed, though without success.

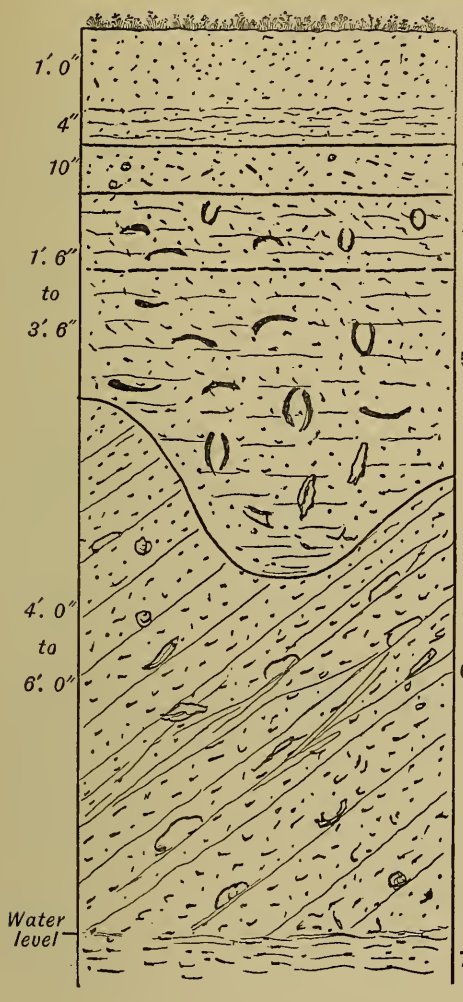
Personally I have not seen the Gomer section for nearly 30 years, as it has always been closed during my many visits to Orford, but Mr. P. F. Kendall has sent me the accompanying sketch (fig. 8), made in 1884, which he is kind enough to allow me to reproduce. One interesting feature of it is the small band of unstratified argillaceous Crag, $1\frac{1}{2}$ to $3\frac{1}{2}$ feet only in thickness, in which he observed a number of lamellibranchs (27 species) with the two valves united, and in the position of growth. *Trophon alveolatus* and *Tr. consocialis*,[3] with other gasteropoda, were commonly found in this bed. Lower down, *Cardium decorticatum* was met with in great abundance. This species occurs also in profusion in the highest part of the Crag at Aldeburgh (see p. 338), and at the Park-gates pit at Sudbourne, but only in the form of casts. Near the water-line at the Gomer section there was a bed of comminuted Crag with many fine gasteropoda, especially a *Brocchia*, almost unknown elsewhere; and many such facts might be adduced to show a want of correspondence in the molluscan fauna of different exposures of the supposed zones.

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 124. In none of my borings did I find any trace of this Gomer shell-bed with abundant univalves.

[2] Mr. Wood, sen., obtained from one pit at Sutton, with a vertical range of a few feet, specimens of nearly all the species known from the Coralline Crag.

[3] These two furnish an example of species which are found at Gedgrave, but not, so far as I know, at Sutton. They occur also at Ramsholt and Boyton.

Fig. 8.—*Section of the Gomer pit (from a sketch made by Mr. P. F. Kendall in* 1884).



1 Made earth, passing into

2 Red loamy sand.

3 White pulverulent Crag with small gasteropoda.
Argillaceous Crag with greatly decomposed shells, passing into

4 Yellow argillaceous Crag, with no trace of bedding, containing many specimens of *Cyprina islandica*, *C. rustica*, and *Panopæa Faujasii*.

5 Crag containing *Cardita senilis*, *Venus casina*, *Astarte Omalii*, *A. Basterotii*, *Trophon consocialis*, *Tr. alveolatus*, *Natica millepunctata*, *Trochus zizyphinus*, *Tr. conulus*, etc. Many of the bivalves have both valves united and the siphonal ends upward.

6 False-bedded Crag made up of comminuted shells. Characterized by abundance of *Turritella triplicata* (*incrassata*) and *Cardium decorticatum*. Contains bands or patches of Pectens, the 3 species *P. maximus*, *P. opercularis*, and *P. tigrinus* being commonly associated.

7 Comminuted Crag, with many rare gasteropoda, notably *Capulus* (*Brocchia*) *partim-sinuosus*.

The following lamellibranchiata were found with both valves united, principally in Bed 5:—

Anomia.
Pecten maximus.
„ *opercularis.*
Modiola.
Pectunculus glycimeris.
Limopsis aurita.
Nucula nucleus.
Leda.
Lucina borealis.
Diplodonta rotundata.
Cardita corbis.
„ *scalaris.*
„ *senilis.*
Cardium decorticatum.
Astarte Basterotii.
„ *Galeottii.*
„ *mutabilis.*
„ *Omalii.*
Cyprina islandica.
Venus casina.
„ *ovata.*
Gastrana laminosa.
Mactra.
Thracia.
Solen ensis.
Panopæa Faujasii.
Mya truncata.

The Gomer beds, regarded by Prestwich as belonging to his zone F, are at a lower level, taking the dip into account, than those at the Broom Hill pit, which he calls D & E. Stratigraphically, therefore, the former, which are within 15 feet of the base of the Crag, in which univalves are abundant, should be placed in zone C; but, according to Prestwich, one of the characteristic features of zone C is said to be the scarcity of such forms.

The Crag of the Gomer field seems to be, up to some height above

the water-level, of the unaltered type, but there is a roadside section (No. 3 in fig. 4), near Butley Ferry, in the immediate neighbourhood, where ferruginous Crag, made up of comminuted material without fossils, comes down almost to the level of the marsh (see fig. 5, p. 328). This belongs to zone G, the upper part of the formation, according to Prestwich, but as such it seems there out of place, being probably within 10 feet of the London Clay. The difficulty disappears if we regard it as merely the altered form of the shelly Crag present in the adjoining field.

At Gedgrave Hall there is a large pit (No. 6) showing about 20 feet of indurated Crag, but immediately below it towards the marsh is another (No. 7) composed of whitish shelly sand, the upper part irregularly coloured by recent infiltration, in which few but the smallest species of mollusca are present, *Nucula nucleus* and *Donax politus* being specially abundant.[1] A boring at this spot was interrupted by tabular layers of limestone, very hard, and difficult to penetrate. These were considered by Prestwich to be distinctive of his zone D. We met with them, however, in no other boring, though they may be occasionally observed elsewhere above the water-line. I look on these bands as purely local, due to infiltration and redeposition of the calcareous matter, and as of no stratigraphical significance.

At the Broom Hill pit (No. 11), near the Keeper's Lodge, so much resorted to by collectors, at which few specimens of gasteropoda are found, the junction of the Crag with the London Clay was only reached at a depth of 22 feet (probably 19 or 20 feet below the marsh). Fragments of large lamellibranchs, and small shells, perfect, were brought up constantly by the borer. Layers of the former seemed to occur at 5 feet, 9 feet, and at the base of the Crag. The upper part of the section exposed at this place has been more or less affected by infiltration. The lowest beds are of a whitish colour, but they gradually become more ferruginous upwards; in places they seem to shade off into each other, so that it is difficult to draw the line between them. Prestwich called the beds at Broom Hill D & E, but if colour be a test, some of them should rather have been placed in his zone G. The section is, however, instructive, showing the process by which the upper part of the Coralline Crag has been transformed.[2]

[1] This is the bed regarded by Mr. Burrows as belonging to zone F; see p. 325.

[2] Among the material brought up by the borer at the Broom Hill pit I noticed the following species:—

Anomia striata.
Ostrea ungulata.
Pecten Gerardii.
„ *tigrinus.*
Pectunculus glycimeris.
Lucina borealis.
Cardita corbis.
„ *scalaris.*
„ *senilis.*
Astarte Basterotii.
„ *Burtinii.*
„ „ var. *pisiformis.*
„ *Galeottii.*
Astarte parvula.
Venus ovata.
„ *casina.*
Cyprina islandica.
Tellina donacina.
Mactra triangula.
Corbula nucleus.

Turritella incrassata.
„ *acutangula.*
Ringicula buccinea.
Adeorbis.

Between the Broom Hill pit and that in Sudbourne Park near the Hall (No. 12), rather more than a mile to the north, the base of the Crag dips still farther, its junction with the London Clay occurring at the latter place at a depth of 31 feet (probably about 27 feet below Ordnance datum). This boring took 4 or 5 days to complete, the difficulty being to extract the loose and wet material. Unless the hole is kept clear as the work goes on, the borer is set fast, and can be regained only with great labour. There was a marked absence of fossils at this spot, little else being brought up but comminuted Crag. No seam of large shells was met with, the only recognizable fragment being a small portion of the hinge of a *Cyprina*, from a depth of 30 feet. The last foot or two of the Crag both here and in other borings was of a bright blue colour.[1]

Exposures of the shelly sands in the Orford district are now confined to the small area between this section and Butley Creek, none being known to me to the north, except the small seam before alluded to in the Bullock-yard pit at Iken, Brick-kiln Farm (No. 27). Prestwich stated, however, that beds belonging to his zones D & F might be found at Iken; but now the Crag there exposed (with the above exception) is in the decalcified and ferruginous condition of the upper part of the formation, that is, of his zone G.

The various sections of the altered Crag show the same difference in character as do those of the lower and unaltered Crag. At one pit it consists of fine material without fossils, except perhaps an occasional valve of *Pecten opercularis*; at another it is crowded with the casts of large shells; while at a third are found layers of reef-building polyzoa in their natural position.

I bored at the pit of ferruginous Crag at Sudbourne Park gates (No. 14), finding comminuted material only, for nearly 20 feet, and to a lower level than that at which the shelly sands occur at the section near the Hall, but without reaching them. The surface of the Crag at this pit (No. 14) is about 33 feet above Ordnance datum; adding to this 27 feet, the approximate depth below Ordnance datum of the base of the formation at pit No. 12, just below, we can ascertain with some approach to accuracy that its total thickness at Sudbourne is 60 feet.[2] It was from Sudbourne that three of the samples of material, Nos. 5, 4, and 6, which were analysed by Messrs. Sutton, were taken, the first being from the upper part of the indurated Crag at section No. 14, the second from the shelly sand in the Hall pit

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These species, coming from the lowest part of the Crag, are all found at higher levels in the immediate vicinity, and at Sutton. At this spot univalves are equally scarce in the 20 feet of Crag above, and in the 20 feet below the water-level, while at the Gomer pit, less than a mile distant, as we have seen, they are very abundant in the same stratigraphical position. If the Gomer beds, containing univalves abundantly, were continuous, we ought to have met with them at other localities in some of our borings, which was not the case.

[1] See p. 323.

[2] This was the estimate originally made by Mr. Wood and myself in 1872, Suppl. 'Crag Mollusca,' Introd. p. iii, Monogr. Palæont. Soc. Prestwich's figures are 83 feet.

(No. 12), and the third from the seam of bright blue stuff brought from the bottom of the boring at the same place.

There is no evidence to show that the Coralline Crag extends either west or east of the main mass of the formation exposed between the rivers Deben and Alde. The Red Crag rests against it, however, on the west side in the parishes of Chillesford and Iken, on the east side near Orford Castle, and at pits 19 & 20 at Sudbourne. Mr. Whitaker states,[1] moreover, that White Crag, considered by him as of Red Crag age, was met with in borings at the Lantern marshes at Orford, resting on the London Clay at a depth of about 30 feet, no Coralline Crag being there present.

Having established the fact of the progressive dip of the junction between the Coralline Crag and the London Clay between Sutton and Sudbourne, and having failed to discover in the beds penetrated any evidence of the continuity of the supposed zones in the outliers at the former locality, it did not seem necessary to carry the borings farther north, especially in view of the increasing difficulty and expense of doing so. As, however, the gradient is more or less uniform where it can be tested, it does not seem improbable that the line separating the two deposits, which can be drawn with accuracy from Sutton to Sudbourne, may be produced towards Aldeburgh and Sizewell also (see fig. 5, p. 328). If this be so, the base of the Crag would be reached at a depth of about 48 feet under the former, and of about 68 feet under the latter place, making the total thickness of the formation 60 feet at Aldeburgh, as it is at Sudbourne.

In the sections (figs. 3, 5, & 7, pp. 324, 328 & 332) I have shown the various positions in which seams of large shells, either perfect or in the form of casts, occur in the unaltered and in the decalcified Crag. I have already stated where they are to be found in the former. In the latter they may be seen at the following, among other localities:—At pit No. 14, near Sudbourne Park gates; at Iken, Nos. 27 & 28; at Aldeburgh, No. 29, close to the river-bank; No. 31, near the railway-station; and at Nos. 32 & 33, farther north. Some of these seams are chiefly composed of the casts of *Cardium decorticatum*, while in others *Cyprina islandica* is the prevailing form. The first-named occur in several places in the upper part of the Crag, as at Sudbourne and Aldeburgh, and it might be supposed that they represent a later, as those containing *Cyprina* represent an earlier zone. At Iken, however (No. 27), midway between those two localities, both forms are present in the rock-bed, though *Cyprina* is by far the most common.[2] These species occur in all parts of the Red Crag, however, and neither of them has any stratigraphical value. In his list of the mollusca of the Coralline Crag, Prestwich remarks of both that they occur *passim*.

My son, W. D. Harmer, has taken two photographs of the sections at Iken (No. 27). The first (fig. 9, p. 340) shows a small patch of shelly

[1] Mem. Geol. Surv. 1886, Aldborough, p. 53.

[2] Mr. Kendall found a bed containing *Cardium decorticatum* abundantly in the lower part of the Crag at Gomer (see p. 334).

sand, about 6 inches thick, and 3 or 4 yards long, which is exposed in the side of a gangway leading down into a deep Crag pit, used as a bullock-yard. In it occur, in the order of their abundance, *Cyprina islandica*, *Cardita senilis*, *Cardium decorticatum*, *Mytilus edulis*, *Venus casina*, and some other of the larger characteristic Crag species, with a few smaller ones, such as *Limopsis aurita*, *Cytherea rudis*, *Venus ovata*, and *Mactra triangula*. They are quite perfect, and in similar condition to those that may be found in the shelly sands at Gedgrave or Sudbourne. The matrix in which they are embedded resembles that of the shelly sands of those localities, being composed of calcareous matter full of minute shell-fragments, and containing much glauconite. It has been to some extent coloured by infiltration from the overlying ferruginous beds, but the fragments of the arragonite-shells and the grains of glauconite have not been affected thereby to any great extent. The same seam is seen in the pit itself (see fig. 10, p. 341) to occur in the midst of the ferruginous rock-bed, but it appears to be gradually losing its unaltered condition,[1] the small shells and the shell-fragments having disappeared, and only the thick and strong specimens, such as *Cyprina*, remaining. Tracing the seam laterally along the sides of the pit, the *Cyprinæ* are replaced by casts, with an occasional valve, almost decomposed, and in a very friable condition.[2]

In another pit at Iken (No. 28), below the last and near the marsh, there is a similar seam of large shells, in the ferruginous rock, but in the form of casts only. These *Cyprina*-beds, which have been supposed to be distinctive of Prestwich's zone D, and which I have traced to the base of the Crag, are thus found to exist also in what is evidently the highest part of the formation.

Beds containing the casts of large shells are found in all the Aldeburgh sections, as at Nos. 29, 31, 32, & 33.[3] At pit No. 31, near the railway-station, the seam is from 4 to 6 feet thick, and contains, in addition to the species found at Iken, specimens of *Voluta Lamberti* (very large) and *Panopœa Faujasii*.[4] Beds of large shells in the form of casts are quite as abundant in the upper part of the Crag at Iken and Aldeburgh (Prestwich's zone G) as the shells themselves are in the lower portion (zone D) at Sutton, Gedgrave, and Sudbourne.[5]

[1] The sharp fracture, when they are broken, of the shells in the gangway (fig. 9) is in striking contrast with the soft and marly condition of some of the specimens in the pit-section (fig. 10).

[2] Mr. Kendall informs me that some years ago, by digging through the floor of the pit of indurated Crag at Aldeburgh (No. 32), he found a number of specimens of *Cardium decorticatum* in a similarly rotten and partly decalcified condition.

[3] At pit No. 34 there is a seam containing specimens of *Mytilus* in great profusion, a form which is by no means so abundant at other localities.

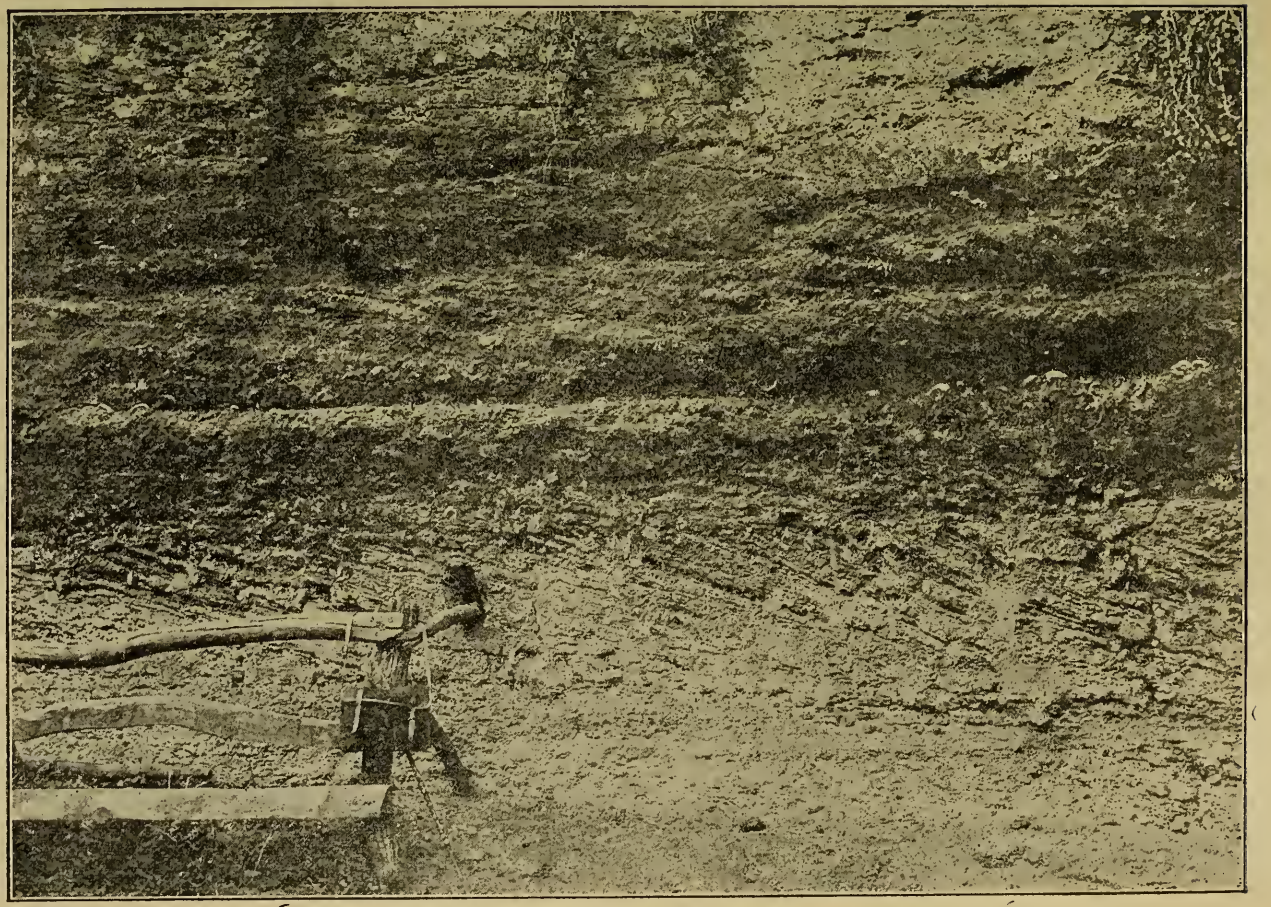
[4] I bored here for 20 feet, through comminuted ferruginous Crag, without reaching the shelly sands.

[5] It has been shown that large species of mollusca occur abundantly in places in the upper or ferruginous part of the Crag. It can hardly be supposed that small forms were absent from the sea of that period, but in material so loose and friable it is less probable that traces of them would be preserved.

Fig. 9.—*Section in gangway leading down to Bullock-yard Pit, Iken.*

[Here a lenticular seam of shelly sand, with perfect shells and comminuted shell-fragments, is included in the ferruginous rock of the highest part of the Coralline Crag.]

Fig. 10.—*Section of the Rock-bed in Bullock-yard Pit, Iken.*



[Here the seam (*xx*) of shelly sand, distinctly seen in fig. 9, passes into ferruginous Crag, but contains occasional valves of *Cyprina*, etc.]

Seams of reef-building polyzoa are present at various localities in the upper part of the Crag (zone G of Prestwich), as, for example, at Aldeburgh (pits 30 & 33), at Iken (pit 24, etc.), and at Sudbourne (pit 18); but this is also the case, as Sir Joseph reminds us, at Sutton, in what he regards as zone E.[1]

At pit 22, where the ferruginous Crag (zone G) is composed simply of comminuted material, specimens of *Fascicularia* are very common, but they occur also at other localities in the unaltered Crag, as at Broom Hill (No. 11), and at Sutton (Prestwich's zones E & F). Generally the Crag along its eastern margin, as at pits 15, 20, 22, & 23, is composed of comminuted material only, the seams of large shells occurring principally in the western portion; this may be accidental, or it may be due to the action of currents varying in strength.

Thus no satisfactory division can be drawn between the shelly sands and the ferruginous rock. We have seen that at one locality (No. 3) the indurated Crag comes down to within 10 feet of the base of the formation, while at another, within a distance of 2 miles (No. 12), the shelly sands have a thickness of 40 feet. It is clear that the rock-bed has been affected by the percolation of acidulated water, as it is in this way that the arragonite-shells have been removed. The irregular line separating the two varieties of Crag may be due therefore to the greater or less depth to which the infiltration has penetrated. That this explanation is the correct one is, I think, proved by the Iken section, where for a short distance only a small portion of the shelly sands has been accidentally protected from its operation.

If, then, the separation between the two principal and apparently self-evident divisions of the formation breaks down, it will add to the difficulty of maintaining the distinction between the remaining zones B, C, D, E, & F, into which Prestwich proposed to divide one of them—divisions which cannot be worked out stratigraphically, and which do not, I submit, represent any distinctive palæontological horizons.

I have discussed the zone-theory of Sir Joseph Prestwich at considerable length, and with much detail, not only because it seems due to so eminent a man to do so, but also because of the great importance of the subject. It is hopeless to attempt to arrive at any clear conception of the history of the older Pliocene period in England, unless we can first ascertain whether this hypothesis, with all its far-reaching consequences, should be accepted or not.

Let us, however, enquire whether there is any evidence in favour of his view that, commencing with a gradual invasion of the English part of the area by the sea (indicated by the basement-bed A), the formation of the Coralline Crag was attended, first by an important subsidence, and then by a re-emergence of the Anglo-Belgian basin. The former is said to have taken place during period B,[2] beds C &

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 119.

[2] *Ibid.* p. 135. Only one exposure of zone B is recorded by Prestwich, namely, a bed at Sutton 4 feet thick.

D being afterwards deposited in a comparatively deep and tranquil sea, which, during period E, is supposed to have attained a depth of from 500 to 1000 feet. Beds F & G were believed by Prestwich to indicate a gradual upheaval, the latter having originated in water sufficiently shallow to allow of the denudation of the older portion of the Crag by current-action, and the heaping-up of the resulting material in the form of submarine banks.

In the first place, I would point out that in no part of the Coralline Crag have we any indication of deep-water conditions. Sir John Murray states that along the continental shores which face the great oceans the sea-bottom is generally covered with mud below the 100-fathom line,[1] and Prof. Herdman finds this mud-zone in the Irish Sea at 50 fathoms.[2] Such deposits are known to all geologists, as for example, in the Argiles bleues of Antibes and the Ligurian coast, where fossiliferous beds have quietly accumulated in deep water near the old shore-line. They are not distinctly stratified as is the Coralline Crag, and the shells are not arranged in layers, but occur here and there at different levels.

Coming nearer home, we have in Belgium the *Isocardia cor*-beds, contemporaneous with the Coralline Crag, which, though not representing deep-sea conditions, are of a character similar to those just mentioned. In them, as M. Van den Broeck informs me, the lamellibranchs are always found with the two valves united, and never arranged in layers. The enormous preponderance of the specimens found in the Coralline Crag consists, on the contrary, of the drifted and stratified remains of dead animals. A few bivalves occur in it double, and some, as at Gomer, in the position of growth ; but there is no reason, on the one hand, why lamellibranchs may not occasionally be found living in sheltered spots on banks of dead shells, nor why, on the other, living shells should not sometimes be carried along the bottom by currents with other débris, and be buried with them. Constant reference is made in the British Association Reports on Dredging to the occurrence of dead mollusca with both valves united,[3] and my son, Dr. S. F. Harmer, informs me that such an occurrence is by no means unusual.

The difference between the *Isocardia*-beds of Belgium and the Coralline Crag is most marked and very instructive. In the one case, we have an ancient sea-bottom, with the mollusca *in situ*, as they lived; in the other, masses of dead shells accumulated by the action of currents. The beds of Prestwich's zone E, which he considers to be indicative of deep-sea conditions, are of the same drifted and stratified character as the rest of the formation.[4]

The mollusca found in the Coralline Crag cannot be regarded as

[1] *Challenger* Reports, Summary, vol. ii. p. 1433.

[2] Rep. Brit. Assoc. (Ipswich) 1895, p. 703.

[3] See, for example, Rep. Brit. Assoc. (Dublin) 1857, List of Shells from Turbot Bank, p. 230.

[4] As to this, see also Clement Reid, Mem. Geol. Surv. 1890, 'Plioc. Deposits of Britain,' p. 36, who says:—'I have been unable to recognize in Prof. Prestwich's division *e* a single stratum unaffected by current-bedding.'

deep-water forms. Many of them have a wide bathymetrical range, but, speaking generally, the fauna belongs, as has often been pointed out, to the Coralline zone of Edward Forbes (15 to 50 fathoms), although a few species characteristic of both deep and shallow water are present. If, however, as I believe, the shells have been drifted, the Coralline Crag fauna indicates the depth of the sea in which the mollusca lived, rather than that of the deposit in which they are embedded.[1]

Prestwich believed that the polyzoan fauna of the Coralline Crag points generally to deep-water conditions, and he specially instanced the genus *Lepralia* (of which many species, according to Busk, occur in it) and some others, as characteristic of deep seas. The classification of the Polyzoa has been much altered of late years, but all the recent species described by Busk as *Lepralia* are found at moderate depths, and he said of them that they have perhaps a greater power of adaptation to different circumstances than is possessed by any other group of these animals.[2] In a letter to Mr. Wood, Busk expressed his opinion that the Crag polyzoa may have lived at any depth from the surface downwards,[3] and with this opinion my son, who has paid much attention to this subject, agrees. Mr. A. W. Waters states, it is true, that in the Bay of Naples the Cyclostomata (polyzoa unprovided with an operculum) are not, as a rule, found in shallow water, though the Cheilostomata often are[4]; but almost all the Crag forms belonging to the first are of extinct species, of whose habits we are ignorant, while the few living Crag species of the latter are said to live in shallow as well as in deep water. Polyzoa are, moreover, quite as abundant in the current-bedded portion of the upper part of the formation, which Prestwich considered was deposited in shallow water, as in those beds which he believed to have originated at a greater depth. Many of the recent polyzoa have, like the mollusca, a wide bathymetrical range, and, at least, it may be said of the Crag forms that they lend little support to the deep-water theory.

No such depth as 500 to 1000 feet is known at present in the southern part of the North Sea, nor in the English Channel. If such a subsidence had occurred during the Crag period, it could not have been local merely, but would have extended either in an easterly or a westerly direction. In the one case it would have caused the submergence of the Miocene beds of North Germany, in the other it would have carried the sea over a great part of the midland counties of England; but of such extensions of the German Ocean during the Pliocene period there is no evidence, and they

[1] On the Turbot Bank, off the Antrim coast, to which reference will be made hereafter, a few deep-water species were found, dead, in 25 to 30 fathoms, which were afterwards discovered living in a deeper and adjoining part of the Irish Sea.

[2] 'Crag Polyzoa,' Monogr. Palæont. Soc. 1859, p. 38.

[3] Suppl. 'Crag. Mollusca,' Introd. p. v, Monogr. Palæont. Soc. 1872.

[4] Quart. Journ. Geol. Soc. vol. xl (1884) p. 681.

seem equally improbable. The Belgian geologists know of no such invasion of their country by the sea. They are rather of opinion that it receded in a northerly direction towards the end of the Diestien period (see map, fig. 1, p. 316). Moreover, such a subsidence, greatly increasing the depth of the North Sea and carrying it over a largely extended area, must have brought about an entirely new set of conditions, with new shore-lines, an altered system of drainage, and sediments as well as currents of a different character.

Alterations in the relative level of land and sea are supposed to take place very slowly, and a depression and re-elevation of such magnitude would probably have been attended not only by the deposition of beds varying in composition and commensurable in importance with the protracted period which they represented, but also by some marked changes in the molluscan fauna. The Pliocene strata of Holland, which are many hundreds of feet in thickness, and have accumulated *pari passu* with the subsidence which has affected that country, are, for example, easily separated into zones, even by the chance specimens found in boring. It seems inconceivable, therefore, that if such vast changes had taken place in the conditions of the Crag basin as those postulated by Prestwich, the Crag fauna would have remained substantially unaltered during the whole time, and that the various stages would have been severally represented by a few feet only of current-caused sediment of the same character throughout, even when tested by chemical analysis. I am not aware that a single fact has been adduced, either by the geologists of England or the Continent, in confirmation of the theory of a great subsidence during the Coralline Crag epoch.

I am equally unable to accept Prestwich's view that at one part of the Coralline Crag period the temperature of Northern Europe fell so considerably as to permit of the presence of floating ice in the Crag basin, bringing boulders into it either from Scandinavia or the Ardennes. This hypothesis, which seems to rest on the otherwise unexplained presence of a single waterworn block of porphyry ('neither angular nor striated')[1] in the basement-bed at Sutton, seems to me at variance both with the fossil evidence and with the probabilities of the case.

Among the extinct species of the Coralline Crag we find, as is well known, a number of genera characteristic of warmer seas than our own, while the recent forms are preponderatingly southern. With one exception, *Buccinopsis Dalei*,[2] a survivor from Miocene times, but not at present known living south of the western coast of Ireland, all the more abundant recent mollusca of the Coralline Crag are now to be found, either in the Mediterranean, or along the Atlantic coasts of France and Portugal, while a third of the number have an exclusively southern range.[3] Purely northern

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 117.

[2] See also Geol. Mag. 1896, p. 27.

[3] There is a similar absence of boreal and arctic shells from the Diestien beds of Belgium.

forms are so rare in the Coralline Crag that, if it were possible to count specimens rather than species, the southern would outnumber the northern by many hundreds, possibly by many thousands, to one.[1]

No ice reaches our shores at the present day either from Scandinavia or Belgium, and the winter temperature of Northern Europe would have to fall considerably before such a condition could arise. As to Scandinavia, the almost entire absence of boreal or arctic shells from the Coralline Crag makes it probable either that the Crag basin was then closed, or at least less open to the north than it is at present (see also p. 350), or that the temperature of Scandinavian seas was affected, as it now is, but to a greater extent, by the warm currents of the Gulf Stream; while, as to Belgium, no similar ice-borne débris occur in the Diestien beds of that country. It should be noticed, moreover, that the block of porphyry in question was not found in the Coralline Crag, but at its base, in a bed full of extraneous fossils and débris, having no distinctive character of their own, forming a medley and heterogeneous group, derived from various Mesozoic as well as Tertiary formations. It seems to me more than probable that the block of porphyry also was derived from some older formation, and that therefore it has no bearing on the question of climate. A similar argument may be applied to the occurrence of those mammalian remains which have been supposed to indicate the character of the land-fauna of the Coralline Crag period. Such fossils, however, occur at the base of the Red Crag also, and this point may be perhaps more conveniently discussed when dealing with that formation.

I entirely agree with those who think that the climate of the Coralline Crag period was warmer and not colder than that of Great Britain at the present day, resembling rather that of the Mediterranean, or even the Azores, and I see no reason for admitting the probability of great climatic changes during any part of it.

[1] Prestwich, however (Quart. Journ. Geol. Soc. vol. xxvii, 1871, p. 135), following Gwyn Jeffreys, who considered them to be identical with the well-known Crag species, tabulated the undermentioned as northern forms of the Coralline Crag:—

Astarte undata (American), Gould = *A. Omalii.* } Extinct species according to
Glycimeris siliqua, Chem. = *Gl. angusta.* } S. V. Wood.

(*A. Omalii* and *Gl. angusta* are both found in the Miocene of Belgium, and therefore can be hardly considered as boreal species.)

Tellina calcarea, Chem. = *T. obliqua.*

(*Tellina calcarea* [*lata*] is, I consider, an entirely distinct form, specially characterizing, moreover, one of the later horizons of the Upper Crag. It is unknown in the Coralline Crag.)

Several other species are mentioned by Prestwich, but either they are rare in the Coralline Crag, or are also found in the Mediterranean or the Lusitanian areas.

Two species of foraminifera are mentioned as northern:—*Lagena globosa* and *L. ornata.* The former is said, by the authors of 'The Foraminifera of the Crag,' to be found in all seas, and to have existed since the Silurian period (p. 177). The latter is unknown from the Coralline Crag. It is found, but rarely, at St. Erth (p. 380) and in the Pliocene of Sicily.

My theory of the Coralline Crag is simpler than Prestwich's. I not only believe with him that in the upper part, but that in the whole of the formation we have the remains of a series of submarine banks. This view, first suggested by Mr. Wood, Sen., in 1863[1], has since been adopted by Mr. C. Reid.[2] I doubt, however, whether these banks originated 'far from shore,' as the latter writer is inclined to think. The bed, a foot thick, observed by Prestwich at Sutton (his zone A) was evidently accumulated under conditions different from those of the rest of the deposit, representing the commencement of the re-invasion of East Anglia by the sea. No trace of any stone-bed was met with in any of the six borings at Gedgrave and Sudbourne in which the London Clay was reached, but this is not conclusive that no such bed exists there, as the borer might possibly in every case have failed to strike a stone, and the nodule-bed certainly occurs at Boyton, only a mile distant from one of them, on the south side of Butley Creek. It seems to me that, with the exception of this thin basement-bed, the Coralline Crag from top to bottom was deposited under more or less uniform conditions, in water sufficiently shallow to be within the reach of currents, at no great distance from the margin of the Crag sea, and in banks which were probably parallel with it. Notwithstanding the slight differences noted by Mr. Sutton between the different samples submitted to him, differences not greater than those to be observed in contiguous parts of the sea-bottom at the present day, the material of which this formation is composed has essentially the same character throughout; and if this be so, it seems that little deposition of sediment took place in the Crag area (or that it was afterwards removed by current-action), until those conditions were established which caused the accumulation of the banks postulated by my theory.

I see no reason for supposing that these conditions differed greatly from those now existing in the German Ocean, or in the shallow seas surrounding the British Isles, except that they were associated with the prevalence of a warmer climate. The present may thus throw light on the past, and if we cannot absolutely restore the geographical features of the Coralline Crag period, we may at least picture to ourselves generally the circumstances under which it must have originated.

In the first place, there is no evidence that beds of dead and drifted shells are now being laid down simultaneously in British Seas over large and continuous areas. Deposits of shelly sand may accumulate, however, in at least two ways: as submarine banks, limited in extent and caused by current-action, or as littoral drift. The former seems to me to represent the conditions attending the deposition of the Coralline Crag, the latter those under which the different Red Crag beds originated. Two examples of the first may be given.

[1] Quoted in 'Foraminifera of the Crag,' Monogr. Palæont. Soc., Introd. p. ii (1866).

[2] Mem. Geol. Surv. 1890, 'Plioc. Deposits of Britain,' p. 41.

Some years ago dredging was carried on rather extensively under the direction of Committees of the British Association for the Advancement of Science. In every case but one recorded by them, a much larger proportion of living than of dead specimens of mollusca were found. On the Turbot Bank before-mentioned, however, 9 species only of the former were found, as compared with 175 of the latter, many of the specimens of the dead lamellibranchs being double.[1] The Turbot Bank stretches from the entrance of Belfast Lough towards the Copeland Islands, and lies at a depth of about 25 to 30 fathoms. It rests against, and gradually shallows towards the shore, extending seaward for a short distance only, and shelving rapidly into deeper water.

The coast of Antrim is separated from the Mull of Cantire by a narrow channel through which the tidal currents run with great velocity. Consequently no deposition takes place there, glacial strata being still exposed at the bottom of the sea, uncovered by more recent beds. The influence of these currents is felt to a considerable depth, so that the dredging operations were sometimes seriously hampered by them. It is to these currents that the accumulation of dead shells farther south, on the Turbot Bank and elsewhere, is due. The shells are swept up by them from the sea-bottom on which the molluscs live, and redeposited, not where the currents are running strongly, but in comparatively sheltered places where their influence is less felt.[2]

The molluscan fauna of the Turbot Bank is of a character zoologically similar to that of the Coralline Crag, nearly all the existing British species known from the latter being common to the two deposits. The percentage of single to double and of dead to living shells is, however, much larger in the Crag.

Some beds, composed almost entirely of organic material, principally the shells, often fragmentary, of dead mollusca, extending over a limited area only, have more recently been discovered near the southern end of the Isle of Man by the Liverpool Biology Committee, and are described in their annual Reports. To these deposits, which are similar in character to the shelly sands of the Coralline Crag, the term 'neritic' has been applied by Prof. Herdman.[3] From him, and from Mr. J. Lomas, F.G.S., of University College, Liverpool, I learn that they are due to the strong currents which sweep through the Calf Sound; that they are not spread evenly over the sea-floor, but occur in the form of banks; and that beds of large shells are often found in one place, and smaller shells in another. Moreover, dead and living shells seldom occur together, and it happens frequently that in spots where molluscan life is most abundant no fossil record of it is accumulating. Most of the mollusca found in the Irish Sea live at a depth of less

[1] Report Brit. Assoc. (Dublin) 1857, p. 230.

[2] Other banks, containing many dead shells and due to the same cause, occur in the immediate neighbourhood, as, for example, 'the Riggs,' situated a mile south of Donaghadee and a mile from land, in about 20 fathoms.

[3] In a letter to me Prof. Herdman speaks of this material as 'recent crag.'

than 50 fathoms. Below that but few occur, except *Isocardia cor*. This mud-loving form is very rare in the Coralline Crag.[1]

Mr. W. H. Wheeler, M.I.C.E., of Boston, in an interesting paper read before the Institution of Civil Engineers in 1896,[2] shows, *inter alia*, 'that the contour of the sea-bed, on a sandy coast, when covered with a moderate depth of water, remains in a stable condition, and that so long as the conditions remain the same, the form of the banks and the depth of the channels are not altered.' He points out that the channels lying between the sandbanks which exist on both sides of the German Ocean at the present day, as in the roadsteads of Calais, Dunkerque, and Ostend on the one hand, and those of the East Anglian coast on the other, have remained without noteworthy alteration for many years. Both the banks and the channels are due to the action of currents, and when they have been once established, and an equilibrium of forces has been set up, no further change can take place until there is some variation in the physiography of the area, such as an elevation or depression of neighbouring land; then a new state of things will arise, and new deposits will accumulate. This, no doubt, is one reason why such well-marked distinctions often exist between succeeding geological zones. The formation of deltas and of deep-sea deposits goes on without intermission, but the sediment of shallow basins affected by currents (like the North Sea at the present time, or, as I believe, its western portion during the Coralline Crag epoch) represents isolated rather than continuous stages in geological history.[3]

The form and alignment of the area now covered by the Coralline Crag are, I think, suggestive. From Tattingstone in the south to the sunken rocks of Sizewell in the north it trends constantly from S.S.W. to N.N.E., with an uniform and slightly-curved outline, parallel to the line forming the north-western boundary of the Red Crag formation, which marks possibly the ancient shore-line of the Crag basin.

The form of the main mass of the Coralline Crag from Gedgrave to Aldeburgh resembles strikingly that of some of the existing sandbanks of the East Anglian coast. Although there has doubtless been much denudation of the Crag between Tattingstone and Sutton, that of the Orford district may still retain to some extent its original form, and may indicate the trend of the coast during the period in question.

The absence of any deposits in East Anglia of the character of the *Isocardia*-beds of Antwerp, that is, of an undisturbed sea-bottom,

[1] Similar banks of dead or broken shells occur in the vicinity of Dungeness. These also are due to current-action, occurring consequently with their longer axes parallel to the coast-line. Other cases of the same kind might be mentioned.

[2] 'Littoral Drift in relation to River-outfalls & Harbour-entrances,' Proc. Inst. C. E. vol. cxxv, pt. 3.

[3] The Pliocene beds of Holland, forming part of the old delta of the Rhine, represent on the contrary, I consider, a continuous sequence.

seems also to indicate that the Coralline Crag is not so much a fragment of a once widely-spread formation as has been often supposed, but one of a series of banks, which existed in a part of the sea where, owing to the bottom being continuously swept by strong currents, no general deposition of sediment was taking place.

The presence of currents causing the accumulation of banks of shelly sand in sheltered spots does not seem so favourable to the growth of mollusca, which flourish most in less exposed situations. Along the convex portion of the Norfolk coast at the present day between Weybourne and Yarmouth, molluscs are but rarely met with; but on the more sheltered part, from Wells to Hunstanton, where the influence of the tidal currents coming from the Lincolnshire coast is less felt, shells lie in places on the beach as thickly as they do in the Crag-beds.

Polyzoa, on the contrary, seem to flourish best in clear water agitated by currents, and their great abundance in the Coralline Crag, not only in the form of comminuted material, but in places in their original position of growth, is especially worthy of notice. D'Orbigny's remarks on the habits of polyzoa, made in 1850, seem to me so applicable to our present enquiry that I venture to quote them in full. He says, 'Qu'ils vivaient dans des eaux agitées, ce qui est prouvé par le manque de sédiments vaseux et surtout par les lits inclinés des couches, comme on le reconnaît si bien sur tous les points, lits inclinés spéciaux aux bancs sous-marins formés par l'action des courants dans les mers anciennes comme dans les mers actuelles.'[1]

The connexion of the Coralline Crag sea with the Atlantic by means of a channel or strait over some part of the South of England seems to be indicated not only by the close correspondence of the mollusca of that formation with those of the Mediterranean,[2] but also because in a closed basin no such currents as those to which I think the deposition of the Coralline Crag was due could have existed.

As we have seen, the currents which attend the flowing tide along the English shores of the North Sea come from the north, and not through the Straits of Dover. The fact of the great subsidence, regularly increasing in a northerly direction, which has affected Holland, and possibly Scandinavia,[3] since the Diestien period is an additional reason for thinking that the Coralline Crag sea may have been less open to the north than it is at present; and if this was so, the velocity of the tidal currents flowing through the southern

[1] 'Paléont. Franç.—Terr. Crétac. (Bryozoaires)' vol. v, p. 11; see also Prestwich, Quart. Journ. Geol. Soc. vol. xxvii. (1871) p. 129.

[2] The correspondence between the existing molluscan fauna of the Mediterranean and that of the Coralline Crag has been often emphasized, but there is also much resemblance between the latter and that of the older Pliocene beds of Italy and Sicily. Many species, of course, occur in the last-named which did not live at that period in our northern latitudes.

[3] There seems to be good reason for supposing that Scandinavia formerly stood considerably higher than it does at present.

channel must have been much greater than it is at present through the Straits of Dover.

The hypothesis that the Coralline Crag represents, not the bottom of a sea in which the mollusca found in it lived (as do the *Isocardia*-beds of Belgium), still less that it originated at any considerable depth,[1] but that it was accumulated by currents coming from the south-west, which heaped up, in comparatively shallow water, the remains of marine organisms, in banks more or less parallel with the then existing coast of the German Ocean, and at some distance from the mouth of any river discharging into it,[2] seems to be in accordance with all the facts of the case. It explains why we find, at the same level, seams, in one place of large, in another of smaller shells, and in a third of fine comminuted material. We can understand that when, by the temporary and local diversion of the currents, no sediment was for a time deposited on any portion of the banks, they would there become occupied by sheets of reef-building polyzoa, which would afterwards be smothered and unable to exist, when another alteration brought over them quantities of the fine mud.[3] Crustaceans and echinoderms would live under such conditions, as they now do on the Turbot Bank, but their numbers would be few in proportion to the drifted shells of mollusca.

For the reasons given above, it seems probable that the conditions under which the Coralline Crag originated were similar to those now obtaining in the northern part of the Irish Sea, where strong tidal currents, sweeping through the narrow channel that separates Ireland from Scotland, are causing the accumulation of banks containing dead shells, at no great distance from the shore and parallel to it.

In a future paper I hope to deal with the questions of the classification and mode of origin of the various deposits of the Upper Crag formation of Suffolk and Norfolk.

IV. Recapitulation.

In the foregoing pages I have set forth the reasons which lead me to think:—

1. That the Lenham Beds, containing a considerable proportion of characteristic Miocene or Italian Lower Pliocene mollusca (13 out of 67) unknown or very rare in the Coralline Crag, are older than that formation.

[1] Our estimate of the depths of the western (and littoral) portion of the Crag basin during the deposition of the Coralline Crag should depend, not on the character of its mollusca, which are not, as a rule, *in situ*, but on the view that we may take as to the strength and volume of the currents then prevailing.

[2] The Thames, in its present form, had not at that time, I consider, come into existence.

[3] Mr. Kendall reminds me that valves of *Pecten*, etc., encrusted with adnate polyzoa, occur chiefly in those parts of the Crag where the reef-building forms are found. These also could exist only when the currents passing over that portion of the area were free from sediment.

2. That the Lenham Beds had probably been upheaved, consolidated, and exposed to denudation before the deposition of the Coralline Crag, and may have been, as formerly suggested by Prof. Ray Lankester, the source from which the boxstones found at the base of the Suffolk Crag have been derived. These boxstones contain a fauna, not identical with, but possessing the same general character as that of Lenham, that is, an admixture of distinctive Miocene and Coralline Crag species.
3. That in the interval between the deposition of the Lenham Beds and the Coralline Crag the Crag sea retired, in consequence of the upheaval of the southern part of the area, to the north, as it did also in Belgium towards the close of the Diestien period.
4. That the Lenham Beds are most nearly, though not exactly, represented by the zone à *Terebratula grandis* of Belgium, and possibly by some fossiliferous deposits recently discovered at Waenrode, near Diest, while the Coralline Crag corresponds very closely with the Belgian zone à *Isocardia cor*.
5. That the Coralline Crag between Sutton and Aldeburgh does not rest upon the horizontal surface of the London Clay, as supposed by Prestwich, it being shown by borings that the junction between the two formations dips regularly towards the north-north-east.

.That no satisfactory evidence, whether stratigraphical or palæontological, is forthcoming to show that any divisions to be observed in the Coralline Crag at Sutton are persistent at other localities in the formation.

7. That none of the supposed zones in the Coralline Crag at Sutton have been shown to be characterized by the first appearance in the Crag basin, or by the disappearance from it, of any species of mollusca or foraminifera. On the contrary, that the forms which have been enumerated as specially distinctive of certain horizons are found also in other parts of the Coralline, and often in the Red Crag too.
8. That no great subsidence of the Crag area during the older Pliocene period, as believed by Prestwich, took place. Such a subsidence must have caused the submergence of districts adjoining it either in this country or on the Continent, and for this no evidence exists.
9. That neither the fauna of the Coralline Crag nor the character of the sediment composing it supplies any indication of deep-sea conditions, the sediment consisting almost entirely of the drifted remains of dead mollusca and polyzoa, or of calcareous matter derived from their decomposition, with reefs of living polyzoa in places, and differing from the contemporaneous *Isocardia cor*-beds of Belgium, which represent an undisturbed sea-bottom, with the shells *in situ* as they lived.
10. That there is no evidence of any great changes of climate during the Coralline Crag period: the waterworn block of

porphyry found at the base of the Coralline Crag at Sutton, which was held by Prestwich to indicate the presence of floating ice in the Crag basin, occurring in a bed full of derivatives, and being possibly itself derived from some older formation.

11. That Prestwich's theory of a temperature sufficiently cold to produce floating ice during the Coralline Crag period is in entire opposition to the palæontological evidence, which indicates that the climate was at that time not colder but warmer than the climate of Great Britain at the present day, more nearly approaching that of the Mediterranean or the Azores.
12. That, so far from it being possible to separate the Coralline Crag into eight constant zones, the division of this formation hitherto adopted into shelly incoherent sands and indurated ferruginous rock can no longer be maintained, the latter being merely an altered condition of the former, as proved not only by general considerations, but by the discovery of a section at Iken, showing the two varieties of Crag side by side, and passing into each other.
13. That with the exception of the basement-bed, 1 foot only in thickness, the material of the Coralline Crag is of similar character throughout, being almost entirely organic, with only a small admixture of inorganic matter; nor is any essential difference between the different parts of it distinguishable, either by microscopical examination or chemical analysis.
14. That, excluding the basement-bed before mentioned, the Coralline Crag was throughout accumulated under similar conditions: namely, in the form of submarine banks, caused by currents, which prevented deposition when they ran strongly, but swept up from the sea-bottom the remains of mollusca, etc., redepositing them in more sheltered situations.
15. That such conditions occur at the present day in the Irish Sea, as for example off the Antrim coast, where an accumulation of dead shells, known as the Turbot Bank, has been caused by the tidal currents which sweep with much velocity through the narrow channel separating Ireland from Scotland; and also at the southern end of the Isle of Man, where deposits mainly composed of organic material, called by Prof. Herdman 'neritic,' exist, being similarly caused by a strong current running through the Calf Sound. Sandbanks caused by tidal currents occur along the coast of East Anglia at no great distance from the shore, and more or less parallel to it.
16. That during the deposition of the Coralline Crag, the German Ocean was less open to the north than it is at present, if, indeed, it was not entirely closed, but that it was connected with the Atlantic by a strait or channel over some part of the southern counties of England, through which currents ran strongly, and that the influence of these currents extended

farther into the North Sea than does that of similar English Channel currents from the westward at the present day.

17. That the Red Crag, with which I hope to deal more fully in another paper, was the marginal accumulation of a sea gradually retreating northward and eastward.

18. That, in opposition to the views of Prestwich, who regarded it, with the exception of the Chillesford Beds and 'the unfossiliferous sands of the Crags,' as throughout of the same age, the Red Crag formation includes a continuous sequence of deposits, arranged, however, horizontally, and not vertically, the different beds being found to contain a gradually diminishing proportion of southern, and a gradually increasing number of northern species of mollusca, as we trace them in a northerly and easterly direction.

Discussion.

Mr. Clement Reid congratulated the Fellows on having before them the valuable series of borings made, purely for scientific purposes, by Mr. Harmer. He was unable to agree with the Author that there was at present any sufficient evidence for separating the Lenham Beds from the Coralline Crag, as forming an older zone. The slight differences in percentage of the recent and southern mollusca were due in the first place, he thought, to the unavoidable study of the larger species alone in the ironstone-moulds of Lenham; the smaller mollusca generally give a higher percentage of persistent forms. In the second place, at Lenham, owing to the geographical position, the sea was warmer; and the deposits also resembling those of Italy rather than those of East Anglia, there was necessarily a greater resemblance to the Mediterranean Pliocene fauna. If such very slight differences were sufficient to mark a time-interval between the Lenham Beds and the Coralline Crag, he could not understand why the Author should correlate the Lenham Beds with the 'boxstones,' the small fauna of these containing a far stronger southern and extinct element than was found at Lenham.

Mr. H. W. Burrows considered that, until a critical examination had been made of the somewhat scanty and unsatisfactory molluscan fauna of the Lenham Beds, no satisfactory results could be obtained by comparing slight percentage-differences of the species with those of other deposits for purposes of correlation. The speaker was not convinced by the arguments of the Author in regard to the oneness of the Coralline Crag. Admitting that the evidence for a zonal distribution is not yet complete— neither mollusca nor polyzoa having been studied from that aspect—yet the foraminifera in some important respects confirm the zonal arrangement. This subject had already been dealt with by Mr. Holland and the speaker in the Monograph of the Crag Foraminifera, and, when the general facies of each zone is considered, a marked resemblance is found to exist

in beds referred by Prestwich to the same zone in widely separated areas of the Crag district. On broader lines it was noted that the foraminifera bring into prominence the Italian Pliocene character of the St. Erth Beds, as emphasized in the 'occurrences' appended to the descriptions of the Crag foraminifera.

Mr. P. F. Kendall observed that there were three classes of evidence which had been adduced in support of the zonal division of the Coralline Crag,—stratigraphical, lithological, and palæontological. Mr. Harmer had shown by his borings that the first of these gave results contradictory of Prestwich's views, for beds which had been included in the same zone were found to lie on different horizons. The lithological test seemed equally to fail; the Gomer beds agreed lithologically with a different zone from that to which they had been referred. The speaker had been unable to recognize any clear palæontological distinctions between the several zones. The bands of large shells at Aldeburgh, Gomer, and Ramsholt yielded a fauna having the same general characteristics, though one was nearly at the top of the Coralline Crag, another near the middle, and the third at the base.

Prof. Seeley stated that when, in earlier times, the Crag phosphate-pits were opened over a wide area, he had no difficulty in recognizing two divisions of the Coralline Crag at Ramsholt and Sutton as well defined by mineral character; but there was certainly change, both in stratigraphy and in fossils, as the beds were followed to the north. It might be that the multitude of pits around Ramsholt had made that part of the Coralline Crag best known, and led to the inference that that Crag was older, from its larger fauna. He had seen no facts of superposition to support that view. The fossils varied from place to place, much as the existing life varied when followed along the same coast. He was inclined, when new sources were suggested for the 'boxstones,' to ask whether it was certain that they were in all cases derivative. The rolled condition might be consistent with hardening of the sand around fossils by infiltration of mineral matter. A large percentage of the stones contained fossils which might add a few species to the true fauna of the Crag.

Mr. A. E. Salter, the Rev. J. F. Blake, and Prof. W. W. Watts also spoke.

The Author thanked the Fellows for their patient attention, and in reply to Mr. Reid he pointed out that, although the evidence was incomplete, so far as it went it was decidedly in favour of his contention that the Lenham Beds were older, perhaps considerably so, than the Coralline Crag. The species occurring at Lenham, but not in the Coralline Crag, were generally of an older, and none of them of a newer type. The theory that the Lenham Beds were older was stratigraphically in accordance with the facts to be observed both in England and Belgium, as more fully set forth in his paper. [See also the footnote in brackets, p. 310.]

To Mr. Burrows he replied that he had been trying for many years to find some proof from the mollusca of the existence of the

zones in the Coralline Crag proposed by the late Sir J. Prestwich, but without success. No evidence was offered by Prestwich, except of the most general character, and the features which he regarded as characteristic of certain zones were equally applicable to others. The evidence of the foraminifera did not seem to the Author of much weight. With few exceptions the Crag forms were world-wide in their present distribution, and went back to older Tertiary, Mesozoic, or even Palæozoic times. Quoting from the list published by Mr. Burrows and his colleagues, he showed that the forms regarded by that writer as characteristic of certain zones were equally common in Zone D at one place, in E at another, and in F or G at a third. No attempt had been made to work out the supposed zones stratigraphically, nor was it possible to do so.